Four Lakes Watershed Diagnostic Study

Marshall County, Indiana

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Prepared for:

Four Lakes Lake Association
c/o Adam and Sara King
17051 N. 12th Road
Plymouth, Indiana 46563

Prepared by:

JFNew
c/o Sara Peel
708 Roosevelt Road
Walkerton, Indiana 46574
574-586-3400

FOUR LAKES WATERSHED DIAGNOSTIC STUDY
EXECUTIVE SUMMARY

The Four Lakes, including Cook, Holem, Kreighbaum, and Millpond Lakes, and their 2,865-acre (1,160-ha) watershed are located south of the Plymouth in Marshall County, Indiana. Agricultural row crop and pasture dominate the landscape throughout the watershed accounting for more than 50% of the total cover. Natural landscapes, including forests (19%), wetlands (4%), and open water (14%) cover 37% of the watershed, while residential land use covers an additional 11% of the watershed. Most of the residential development is located adjacent to the lakes.

The distinct geological setting of the Maxinkuckee Moraine in which the lakes and their watershed lie influences the characteristics of the watershed soils. The watershed's steep slopes combined with the till origin of soils increases the potential for soil erosion. Approximately 55% of the watershed is mapped in a highly erodible or potentially highly erodible soil unit. These easily eroded soils form much of the shoreline of the Four Lakes chain. These same factors, as well as a tendency to flood and lack of permeability, limit the functioning of septic systems in the watershed. The Natural Resources Conservation Service rates more than 80% of the soils within the Four Lakes watershed as moderately or severely limited for use as septic system leach fields.

Holem and Millpond Lakes are characterized as shallow lakes (maximum depth approximately ≤ 30 feet), while Cook and Kreighbaum Lakes possess extensive shallow areas. Shallow lake researchers suggest that, in theory, shallow lakes exist in one of two forms: clear, with a dominance of rooted plants or turbid, with a dominance of algae. Kreighbaum and Millpond Lakes possess some characteristics of the clear, well vegetated form of shallow lakes. They support healthy, diverse submerged macrophyte communities. These lakes also exhibit moderate water clarity, relatively low chlorophyll *a* concentrations, and relatively normal nutrient concentrations for Indiana lakes. In contrast, Holem Lake supports a less diverse submerged plant community and relatively high chlorophyll *a* concentration. This lake also exhibits relatively poor clarity in comparison to the other lakes. While this lake is not devoid of vegetation, it may be on its way toward the turbid, unvegetated state. Additionally, several nuisance species, including Eurasian water milfoil, curly leaf pondweed, purple loosestrife, reed canary grass, and giant reed, occur in and around the lakes.

In general, the Four Lakes can be considered moderately to highly productive. Historical data for Cook Lake suggests that water quality within the lake has declined and that the lake is best described as eutrophic to hypereutrophic. Data suggests that Holem and Kreighbaum Lakes have changed somewhat over time, but that there is no exact trend in water quality. Both lakes can be described as mesotrophic to eutrophic. Mill Pond Lake may best be described as eutrophic to hypereutrophic as indicated by both historic and current water quality data.

To address the concerns identified in the study, several lake and watershed management techniques are recommended. These include: completing an aquatic plant management plan; implementing a biological control program for purple loosestrife; protecting and preserving watershed wetlands; enrolling row crop agriculture parcels in the Conservation Reserve Program; implementing individual property owner Best Management Practices; and installing sewer or alternative wastewater treatment systems around the Four Lakes.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

Cook, Holem, Kreighbaum, and Millpond Lakes, collectively known as the Four Lakes, are part of a chain of kettle lakes covering more than 460 acres (186.1 ha) within the Yellow River watershed south of Plymouth, Indiana (Figure 1). The Four Lakes watershed stretches out to the north, east, and south of the lakes covering approximately 2,865 acres (1,160 ha; Figure 2). Specifically, the lakes and their watershed are located in Sections 13-16 and 22-24 in Township 33 North, Range 1 East and Sections 18-20 and 30 in Township 33 North, Range 2 East. Water generally flows east to west from Cook and Holem Lakes to Kreighbaum and Millpond Lakes. Water from the Four Lakes discharges through Millpond Lake's outlet at the west end of the chain of lakes to Harry Cool Ditch. Water from Harry Cool Ditch flows northwest before emptying into Eagle Creek, which combines with the Yellow River east of Knox, Indiana. The Yellow River transports water to the Kankakee River, which empties into the Illinois River, ultimately reaching with the Mississippi River in southwestern Illinois.

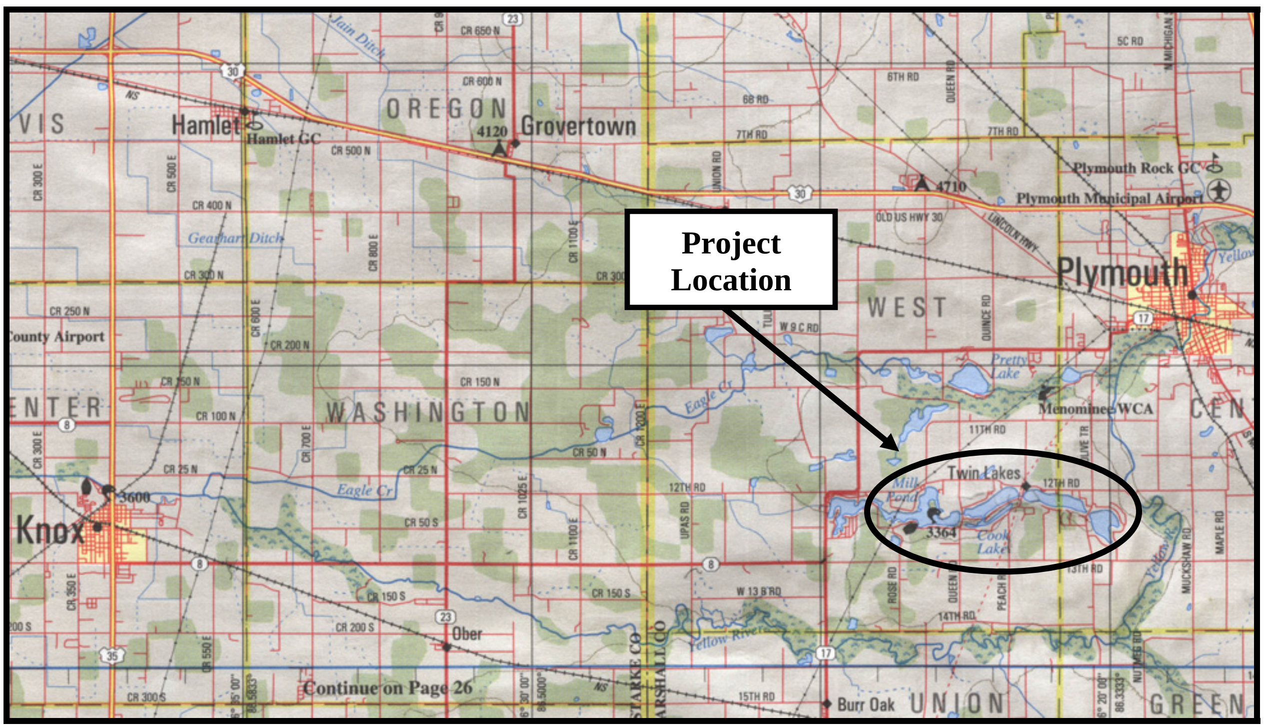

Figure 1. General location of the Cook, Holem, Kreighbaum, and Millpond Lakes, or Four Lakes, watershed.
Source: DeLorme, 1998. Scale: 1"=approximately 2.5 miles'.

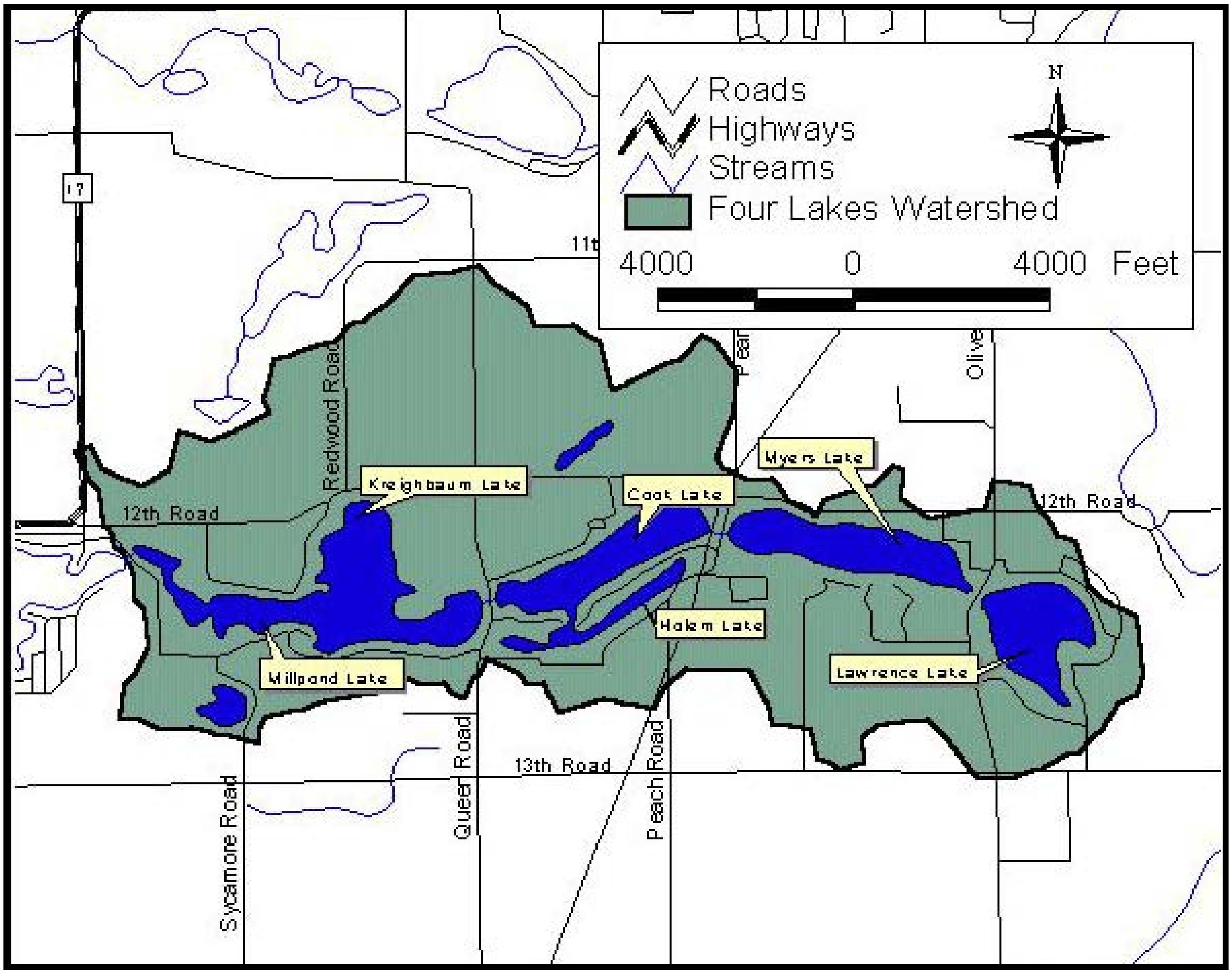

Figure 2. The Four Lake watershed.
Source: See Appendix A. Scale: 1”=4,000’.

The Four Lakes have historically exhibited moderately good water quality. The lakes’ water clarity is generally better than other lakes in the region. Chlorophyll *a* concentrations were generally better in Holem and Kreighbaum Lakes than lakes in the region; however, historic chlorophyll *a* concentrations were generally worse in Cook and Millpond Lakes than other lakes in the region. Conversely, all of the lakes contained higher total phosphorus concentrations than lakes in the region.

Cook and Holem Lakes’ water quality has changed greatly over time. Historical records from the past 35 years indicate that Cook Lake’s transparency declined from 10.5 feet (3.2 m) to 2.3 feet (0.7 m) before improving again in 2004. Cook Lake’s nutrient levels follow similar patterns reaching their highest concentrations in 1995. A plankton bloom and the associated high Trophic State Index (TSI) score indicates that water quality was generally poor at this time. Since 1995, water quality has improved in Cook Lake, resulting in the highest water quality observed in the lake in 35 years. Holem Lake’s water quality exhibits nearly the exact opposite pattern of that observed at Cook Lake. Secchi disk transparency ranged from 8.5 feet (2.6 m) to 11.5 feet (3.5 m) from the 1970 to l999. Water quality has declined in the last five years resulting in the lowest transparencies recorded at Holem Lake occurring during this study. Nutrient and chlorophyll *a* concentrations follow a similar pattern; however, current concentrations are lower than those observed in most Indiana lakes.

Like Cook and Holem Lakes, the water quality of Kreighbaum and Millpond Lakes fluctuated between sampling events covering the past 35 years. However, water quality within Kreighbaum and Millpond Lakes during the current study appears to be similar to that observed in the 1970s. Kreighbaum Lake's water clarity has declined since the 1970s, but has been consistently greater than 5.6 feet (1.7 m) which is the regional median (CLP data files, unpublished). Kreighbaum Lake's nutrient concentrations have remained relatively normal for Indiana lakes over the past 35 years. However, total phosphorus concentrations exceed the Indiana state median value. Water quality fluctuates within Millpond Lake. The lake's water clarity ranged from 1.6 feet (0.5 m) to 9.0 feet (2.7 m) over the last 35 years. The poorest water clarity coincides with an algae bloom which occurred in 1995 at both Millpond and Cook Lakes. Phosphorus concentrations, plankton densities, and the Indiana TSI score indicate that in 1995 water quality within Millpond Lake was the poorest observed historically. Current trends indicate that water clarity is improving and nutrient concentrations are declining within Millpond Lake.

The shallow nature of the Four Lakes provides ample surface area for the growth of aquatic plants. Early records of the area suggest that much of the lakes' shorelines and shallow areas were covered by emergent aquatic plant growth (Blatchley, 1900; McDonald, 1908; Robertson, 1971). Blatchley (1900) describes the shoreline of Cook and Holem Lakes as small, marshy ponds with wide areas of marshy growth between the open water of the lakes and their steep shorelines. Kreighbaum Lake originally existed as a small, relatively round lake which covered the open water area currently observed. The emergent wetland located around the islands separating Kreighbaum and Millpond Lakes was originally considered outside of the lake's shoreline. However, when the Lake Latonka dam was constructed, the emergent wetland was inundated and the lake's shoreline expanded to include these shallow areas. Millpond Lake has been historically shallow. Millpond Lake was originally created by damming Forge Creek at Rose Road to run Marshall County's first grist mill. Zehner Millpond or Millpond Lake, as it is currently known, was described as a shallow, marshy pond (Swindell, 1923).

The productive nature of the lakes, their shallow nature, and heavy plant cover combine to produce a high quality fishery. Fisheries surveys conducted by the Indiana Department of Natural Resources (IDNR) show that gamefish production is high within the lakes. Gamefish dominate the total biomass of the lakes' fishery accounting for 50 to 70% of the fishery by weight in 2002 and 2003 (Price and Robertson, 2003; Price, 2004). Lower quality fish that typically adapt to poor water quality like carp and white sucker have not been observed in the Four Lakes.

Despite the lakes' relatively good water quality and their ability to provide good fishing, lake residents, particularly long-time residents, have noted an increase in density and a decline in diversity of aquatic vegetation within and around the lakes. Specifically, submerged vegetation, including nuisance species such as Eurasian water milfoil and curly leaf pondweed, appears to have expanded its coverage within the Four Lakes. Residents also cited the presence of purple loosestrife along a majority of Cook, Holem, Kreighbaum, and Millpond Lakes' shoreline and within shallow areas of lake as their other main concern. Residents have noted a decline in the lakes' depth due to siltation and the accumulation of plant material. Residents noted poorer water quality as a concern as well. These changes have negatively impacted the residents' enjoyment of the lake and increased their desire to protect the lakes' health and future.

Four Lakes residents began working to improve the aesthetics and water quality of their lakes in 2001. Since that time, the residents have taken a more active role in the management of their lakes. For the past three years, the Four Lakes Lake Association has combined financial resources and has hired one applicator to treat plants within each of the lakes. Individual residents have worked with the Indiana 4-H Program to release biological control agents to help control the purple loosestrife population and reduce the spread of purple loosestrife around the lakes. Residents also participate in the Indiana Clean Lakes volunteer monitoring program. While these practices have likely slowed the spread of nuisance species within the lakes, they do not address all of the areas of concern identified by lake residents. Additionally, lake residents wish to understand the processes that they as individuals and as a group can use to improve water quality and aesthetics within the Four Lakes. To achieve these goals, the Four Lakes Lake Association applied for and received funding from the IDNR Lake and River Enhancement Program (LARE) to complete a diagnostic study of the lakes.

The purpose of the diagnostic study was to describe the conditions and trends in Cook, Holem, Kreighbaum, and Millpond Lakes and their watershed, identify potential problems, and make prioritized recommendations addressing these problems. The study consisted of a review of historical studies, interviews with lake residents and state/local regulatory agencies, the collection of current water quality data, pollutant modeling, and field investigations. In order to obtain a broad understanding of the water quality in the Four Lakes and that flowing between the lakes, the diagnostic study included an examination of the lakes' water chemistry and their biotic communities (plankton and macrophytes) which tend to reflect the long-term trends in water quality. This report documents the results of the study.

2.0 WATERSHED CHARACTERISTICS

2.1 Physical Characteristics

Figure 3 shows the approximate subwatersheds for each of the Four Lakes. Each distinctly shaded region represents the portion of land draining directly to the lake for which the subwatershed is named. It is important to note that some of the lakes also receive water from other lakes located upstream; thus a lake's total watershed may be larger than the area shaded as its subwatershed on Figure 3. For example, Cook Lake receives direct drainage from the area of land shaded in green. It also receives water from Holem Lake (represented in pink). This means that Cook Lake's total watershed size is 1,520 acres (615.2 ha), represented in green, plus 218.3 acres (88.4 ha), represented in lavender for a total of 1,738.4 acres (703.5 ha). Similarly, Millpond Lake receive drainage from Cook (green), Holem (pink), and Kreighbaum (blue) Lakes plus the area that is shaded yellow for a total watershed of approximately 2,864 acres (1,160 ha). Table 1 summarizes the direct subwatershed size, total watershed size, and watershed area to lake area ratios for each lake.

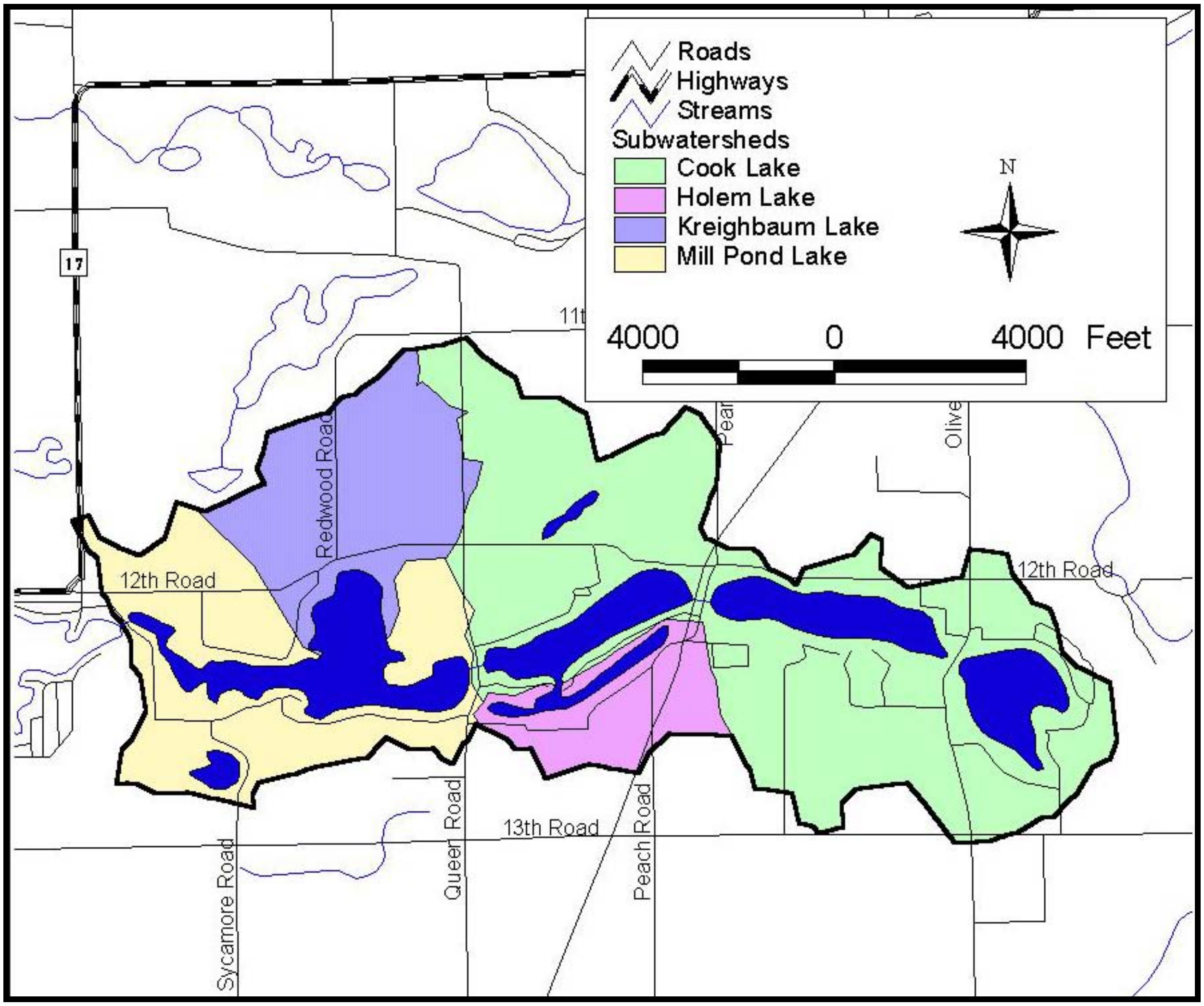

Figure 3. Four Lakes subwatersheds.
Source: See Appendix A. Scale: 1"= 4,000'.

Table 1. Watershed and subwatershed size for the Four Lakes.

Lake	Direct Subwatershed Size	Total Watershed Size	% of Four Lakes Watershed	Watershed Area: Lake Area
Cook Lake	1,520.1 ac (615.2 ha)	1,738.4 ac (703.5 ha)	53%	18.7:1 18.6:1*
Holem Lake	218.3 ac (88.4 ha)	218.3 ac (88.4 ha)	8%	5.4:1 4.7:1
Kreighbaum Lake	464.4 ac (188.0 ha)	464.4 ac (188.0 ha)	16%	11.9:1 10.9:1
Millpond Lake	661.4 ac (267.8 ha)	2,864 ac (1,160 ha)	23%	22.2:1 18.9:1
Entire Four Lakes Watershed Area:All Lakes Area				9.5:1

*The second ratio indicates the watershed area:lake area ratio excluding all of the surface water acreage from the overall watershed acreage.

Watershed size and watershed area to lake area ratios can affect the chemical and biological characteristics of a lake. For example, lakes with large watersheds have the potential to receive greater quantities of pollutants (sediment, nutrients, pesticides, etcetera) from runoff than lakes with smaller watersheds. For lakes with large watershed area to lake area ratios, watershed activities can potentially exert a greater influence on the health of the lake than lakes possessing small watershed to lake ratios. Conversely, for lakes with smaller watershed area to lake area ratios, shoreline activities and internal lake processes may have a greater influence on the lake's health than lake with large watershed area to lake area ratios.

The Four Lakes possess a small watershed (2,864 acres or 1,160 ha) resulting in a small watershed area to lake area ratio (9.5:1). Holem Lake, which possesses the smallest watershed of any of the Four Lakes, also possesses the smallest watershed area to lake area ratio (5.5:1). Holem Lake's low ratio results from the lake's position within the landscape; the lake is located in the headwaters of the Four Lakes watershed, so very little area drains into it. Conversely, Cook, Kreighbaum, and Millpond Lakes possess watershed area to lake area ratios higher than that observed at Holem Lake (18.7:1, 10.9:1, and 17:1, respectively). The Four Lakes all possess ratios greater than the ratio calculated for Myers and Lawrence Lakes (5:1; JFNew, 2000), but are typical for glacial lakes. Many glacial lakes have watershed area to lake area ratios of less than 50:1. Watershed area to lake area ratios on the order of 10:1 are fairly common for glacial lakes. For comparison, watershed area to lake area ratios for reservoirs typically range from 100:1 to 300:1 (Vant, 1987). As a result of these high watershed area to lake area ratios, watershed activities can potentially exert a greater influence on the health of the lake than shoreline activities and in-lake processes. For the Four Lakes, which possess low watershed area to lake area ratios, it is likely that shoreline activities and in-lake processes likely exert a larger influence over water quality within the lakes than the influence generated by the lakes' watershed.

2.2 Climate

Indiana Climate

Indiana's climate can be described as temperate with cold winters and warm summers. The National Climatic Data Center summarizes Indiana weather well in its 1976 Climatology of the United States document no. 60: "Imposed on the well known daily and seasonal temperature fluctuations are changes occurring every few days as surges of polar air move southward or tropical air moves northward. These changes are more frequent and pronounced in the winter than in the summer. A winter may be unusually cold or a summer cool if the influence of polar air is persistent. Similarly, a summer may be unusually warm or a winter mild if air of tropical origin predominates. The action between these two air masses of contrasting temperature, humidity, and density fosters the development of low-pressure centers that move generally eastward and frequently pass over or close to the state, resulting in abundant rainfall. These systems are least active in midsummer and during this season frequently pass north of Indiana" (National Climatic Data Center, 1976). Prevailing winds in Indiana are generally from the southwest but are more persistent and blow from a northerly direction during the winter months.

Four Lakes Watershed Climate

The climate of Marshall County is characteristic of northern Indiana exhibiting warm summers and cold and snowy winters. Winters in Marshall County typically provide enough precipitation, in the form of snow, to supply the soil with sufficient moisture to minimize drought conditions when the hot summers begin. Winters are cold in Marshall County, averaging 27º F (-2.8º C), while summers are warm, averaging 71º F (21.7º C). Marshall County's highest recorded temperature was 109º F (42.8º C) on June 20, 1953. Mild drought conditions occur occasionally during the summer when evaporation is highest. Historic data from 1951 to 1974 suggest that the growing season (defined as days with an air temperature higher than 40º F or 4.4º C) in Marshall County is typically 139 days long, although it can last as long as 164 days (Smallwood, 1980). The last day of freezing temperatures in spring usually occurs around May 6, while the first freezing temperature in the fall occurs around October 5. During summer, average relative humidity differs greatly over the course of a day averaging 80% at dawn and dropping to an average of 60% in mid-afternoon. The average annual precipitation is 38.52 inches (97.8 cm). Table 2 displays average annual precipitation data for Marshall County as well as precipitation data for 2004. In 2004, approximately 40 inches (101.6 cm) of precipitation (Table 2) was recorded at Plymouth in Marshall County. When compared with the 30-year average for the area, the 2004 annual rainfall exceeded the average by approximately 1.5 inches (3.8 cm).

Table 2. Monthly rainfall data for year 2004 as compared to average monthly rainfall. Current data (2004) is based on rainfall as measured in Plymouth, Indiana; averages are based on available weather observations taken during the years of 1971-2000.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2004	1.24	0.70	2.64	0.64	7.31	3.99	4.08	8.00	1.76	2.27	4.74	2.72	40.09
Marshall	1.92	1.84	2.87	3.87	3.79	4.20	4.10	3.33	3.62	3.02	3.03	2.93	38.52

Source: Purdue Applied Meteorology Group, 2004.

2.3 Topography and Geology

The advance and retreat of the glaciers in the last ice age shaped much of the landscape observed in Indiana today. As the glaciers moved, they laid thick till material, or ground moraine, over much of the northern two thirds of the state. This ground moraine left by the glaciers covers much of the central portion of the state. In the northern portion of the state, ground moraines, end moraines, lake plains, and outwash plains create a more geologically diverse landscape compared to the central portion of the state. End moraines, formed by the layering of till material when the rate of glacial retreat equaled the rate of glacial advance, add topographical relief to the landscape. Distinct glacial lobes, such as the Michigan Lobe, Saginaw Lobe, and the Erie Lobe, left several large, distinct end moraines, including the Valparaiso Moraine, the Maxinkuckee Moraine, and the Packerton Moraine, scattered throughout the northern portion of the state. Glacial drift and ground moraines cover flatter, lower elevation terrain in northern Indiana. Major rivers in northern Indiana cut through sand and gravel outwash plains. These outwash plains formed as the glacial meltwaters flowed from retreating glaciers, depositing sand and gravel along the meltwater edges. Lake plains, characterized by silt and clay deposition, are present where lakes existed during the glacial age.

The Four Lakes watershed lies within the southern portion of the Maxinkuckee Moraine (Figure 4). The Maxinkuckee Moraine is a crescent shaped moraine covering approximately 30 to 40 miles of western Marshall County and portions of western St. Joseph and Fulton Counties. The Maxinkuckee Moraine formed when the Huron-Saginaw Lobe of the last Wisconsin Age glacier stalled during its last northeasterly retreat (Wayne, 1966). Movement of the Lake Michigan Lobe from the northwest may have influenced the moraine's formation as well (IDNR, 1990).

The moraine covers Antrim shale bedrock, which lies under the entire Four Lakes watershed. This bedrock shale is from the Devonian-Mississippian Period (Gutschick, 1966).

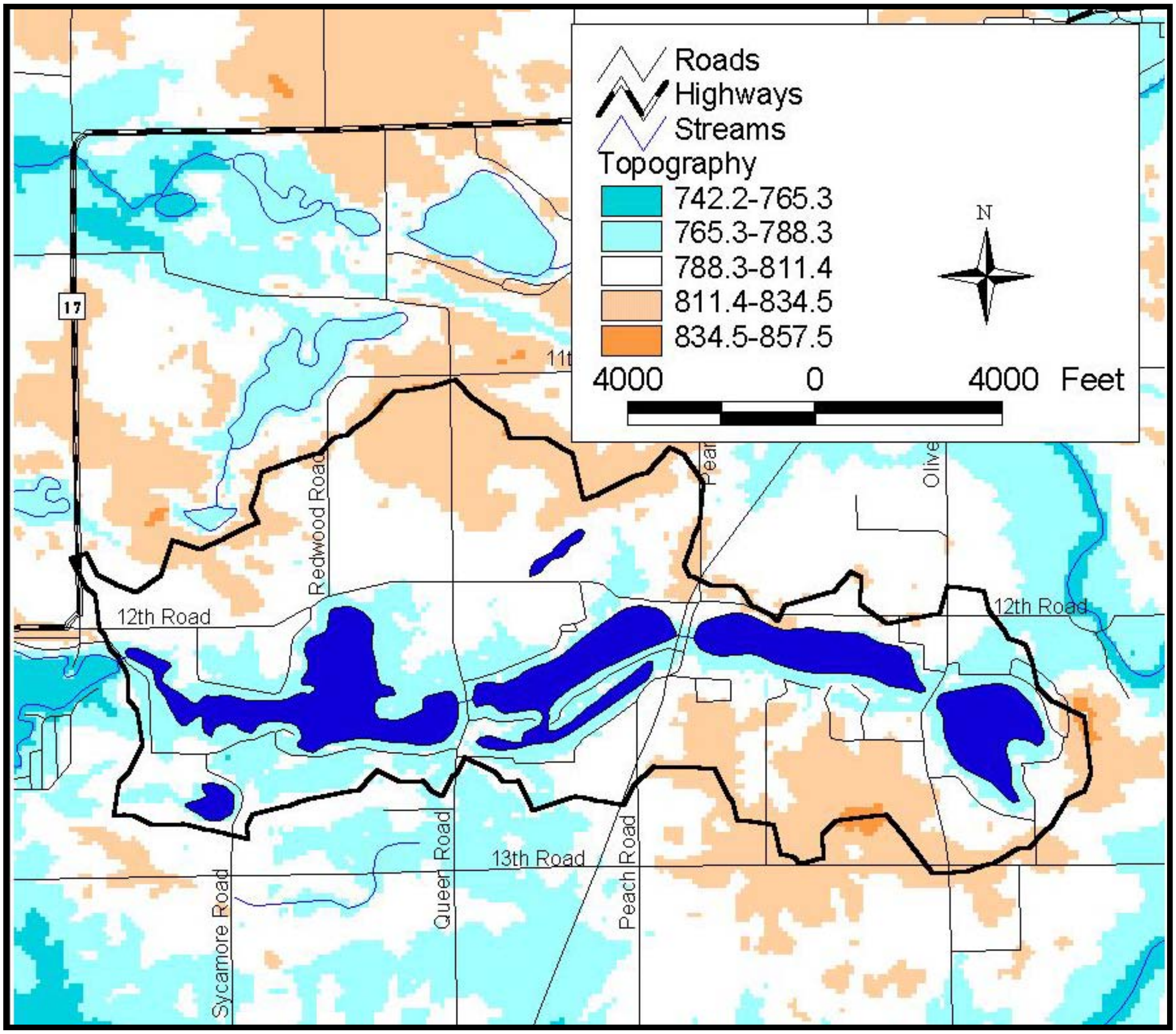

Figure 4. Topographic relief of the Four Lakes watershed. Topographic elevations are given in feet mean sea level.
Source: See Appendix A. Scale: 1"= 4,000'.

The watershed's geologic history is responsible for the watershed's topography (Figure 4). As noted previously, the Four Lakes, with the exception of Millpond Lake, are kettle lakes, part of the characteristic knob and kettle topography of end moraines. Kettle lakes are depressions in the glacial outwash left behind after partially-buried ice blocks melt, filling the depressions with water. The lakes occupy the low spot in the watershed at 768 feet (234 m) above mean sea level (MSL). The highest elevations in the watershed reach over 850 feet (259 m) above MSL and lie along the eastern and southern watershed boundaries near Lawrence Lake where the Huron-Saginaw Lobe of the last glacial age left end moraines (Figure 4). As with most watersheds, the steepest slopes exist in the upper watershed. Steep slopes occur east of Lawrence Lake forming the eastern watershed boundary. The northwestern and southeastern portions of the watershed gradually slope down to the lakes. Slopes bordering the shorelines of the Four Lakes tend to be steeper than surrounding topography. Historical maps and the hydric soil map suggest that much of the area in the immediate vicinity of the Four Lakes was historically wetland.

The geology and resulting physiography of the Four Lakes watershed typify the physiographic region in which the watershed lies. The Four Lakes watershed lies within Malott's Northern Moraine and Lakes Region. Specifically, the watershed lies within the Kankakee Outwash and Lacustrine Plain (Schneider, 1966). The Kankakee Outwash and Lacustrine Plain is characterized by low, poorly drained areas underlain mostly by sand. Wisconsin Age glaciers deposited a majority of the sand via outwash and meltwater. Thick gravel deposits below or interspersed with the sand originated from valley trains and glacial outwash. Prevailing westerly winds modified the topography of the plain through sand redistribution over the past 12,000 years. The result is a broad, flat, featureless sand plain intersected by shallow kettle depressions and sand piles or dunes.

2.4 Soils

The soil types found in Marshall County are a product of the original parent materials deposited by the glaciers that covered this area 12,000 to 15,000 years ago. The main parent materials found in Marshall County are glacial outwash and till, lacustrine material, alluvium, and organic materials that were left as the glaciers receded. The interaction of these parent materials with the physical, chemical, and biological variables found in the area (climate, plant and animal life, time, landscape relief, and the physical and mineralogical composition of the parent material) formed the soils of Marshall County today.

The Four Lakes watershed's geological history described in the previous section determined the soil types found in the watershed and is reflected in the major soil association that covers the Four Lakes watershed. Before detailing the major soil association covering the Four Lakes watershed, it may be useful to examine the concept of soil associations. Major soil associations are determined at the county level. Soil scientists review the soils, relief, and drainage patterns on the county landscape to identify distinct proportional groupings of soil units. The review process typically results in the identification of eight to fifteen distinct patterns of soil units. These patterns are the major soil associations in the county. Each soil association typically consists of two or three soil units that dominate the area covered by the soil association and several soil units that occupy only a small portion of the soil association's landscape. Soil associations are named for their dominant components. For example, the Riddles-Metea-Wawasee association consists primarily of Riddles sandy loam, Metea loamy fine sand, and Wawasee sandy loam.

Smallwood (1980) maps one soil association in the Four Lakes watershed: the Riddles-Metea-Wawasee association. This soil association is characteristic of morainal areas in Marshall County, such as the Maxinkuckee Moraine. Soils in this association developed from glacial till parent materials. In general, Riddles soils account for approximately 54% of the total soils in the association; Metea soils account for 22%, while Wawasee soils comprise 13% of the soil association. Much of the remaining portion of the soil association consists of hydric soil components which line drainageways and surround the Four Lakes including Fluvaquents, Brookston loam, Rensselaer loam, and Whitaker loam soils. Riddles and Wawasee soils occupy moraine ridges, while Metea soils occur on low knolls and sides of moraines. Woodlands and forested areas thrive on the Riddles-Metea-Wawasee association. The soils' strong slopes may limit agricultural productivity. Steep slopes and moderately fine subsoil textures limit the usage of these soils for septic absorption fields.

Soils in the watershed, and in particular their ability to erode or sustain certain land use practices, can impact the water quality of lakes and streams in the watershed. The dominance of Riddles and Wawasee soils across the Four Lakes watershed suggests much of the watershed is prone to erosion; common erosion control methods should be implemented when the land is used for agriculture or during residential development to protect waterbodies in the Four Lakes watershed. Similarly, soils that are poorly suited to serve as septic system leach fields cover a large portion of the Four Lakes watershed, including the heavily populated shorelines at the Four Lakes. The coupling of high density residential land use with soils that are poorly suited for treating septic tank effluent is of concern for water quality in the Four Lakes watershed. More detailed discussion of highly erodible soils and soils used to treat septic tank effluent in the Four Lakes watershed follows below.

2.4.1 Highly Erodible Soils

Soils that erode from the landscape are transported to waterways where they degrade water quality, interfere with recreational uses, and impair aquatic habitat and health. In addition, such soils can carry attached nutrients, which further impair water quality by increasing production of plant and algae growth. Soil-associated chemicals, like some herbicides and pesticides, can kill aquatic life and damage water quality.

Highly erodible and potentially highly erodible are classifications used by the Natural Resources Conservation Service (NRCS) to describe the potential of certain soil units to erode from the landscape. The NRCS examines common soil characteristics such as slope and soil texture when classifying soils. The NRCS maintains a list of highly erodible soil units for each county. Table 3 lists the soil units in the Four Lakes watershed that the NRCS considers to be highly erodible and potentially highly erodible.

Highly erodible and potentially highly erodible soil units in the form of Wawasee, Riddles, and Oshtemo soils cover much of the Four Lakes watershed. Areas of the watershed that are mapped in these soil units and have gentle slopes are considered moderately limited for agricultural production. As slope increases, the severity of the limitation increases. Some steeply sloped Wawasee, Riddles, and Ostemo soils are considered unsuitable for agricultural production due to erosion hazard. The erosion hazard would also exist during residential development on these soils.

Table 3. Highly erodible and potential highly erodible soils units in the Four Lakes watershed.

Soil Unit	Status	Soil Name	Soil Description
ChC	PHES	Chelsea fine sandy loam	2-6% slopes
FsB	PHES	Fox sandy loam	2-6% slopes
FsC2	PHES	Fox sandy loam	6-12% slopes, eroded
MeB	PHES	Martinsville loam	2-6% slopes
MgC	PHES	Metea loamy fine sand	2-6% slopes
OsB-OsC	PHES	Oshtemo loamy sand	2-12% slopes
OsD	HES	Oshtemo loamy fine sand	12-18% slopes
PsC-PsD	PHES	Plainfield sand	3-18% slopes
RsB	PHES	Riddles sandy loam	2-6% slopes
RsC2	PHES	Riddles sandy loam	6-12% slopes, eroded
RsD	HES	Riddles sandy loam	12-18% slopes
WkB	PHES	Wawasee sandy loam	2-6% slopes
WkC2	PHES	Wawasee sandy loam	6-12% slopes, eroded
WmD3	HES	Wawasee sandy clay loam	12-18% slopes, severely eroded

Note: PHES stands for potentially highly erodible soil and HES stands for highly erodible soil.

As Figure 5 indicates, potentially highly erodible soils cover a substantial portion (1,242.1 acres (502.6 ha) or nearly 44%) of the Four Lakes watershed. This acreage is spread throughout the watershed. Highly erodible soil exists on approximately 225.8 acres (94.1 ha or nearly 8%) of the watershed. Highly erodible soils surround nearly the entire shorelines of Myers and Lawrence Lakes, border the northeastern shoreline of Cook Lake and the northwestern shoreline of Holem Lake, and covers the entirety of the ridge separating Cook and Holem Lakes. Additionally, highly erodible soils surround the northwestern bay of Millpond Lake and cover much of the area around Thomas Lake. Because the large majority of land mapped as highly erodible or potentially highly erodible are located along the lakes' shorelines, special planning and the use of best management practices (BMPs) are needed during residential development projects to ensure minimal erosion.

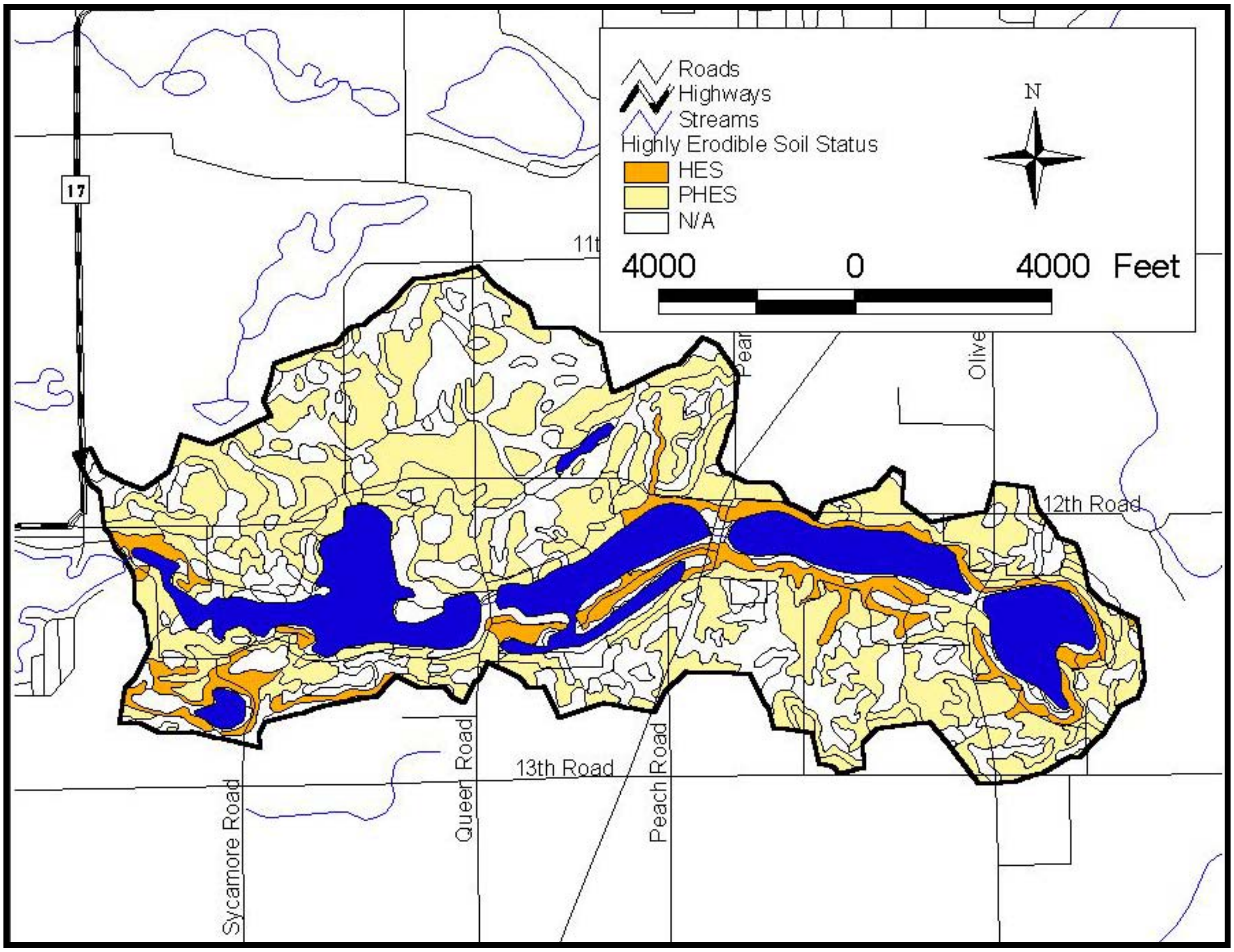

Figure 5. Highly erodible and potentially highly erodible soils within the Four Lakes watershed.
Source: See Appendix A. Scale: 1"= 4,000'.

2.4.2 Soils Used for Septic Tank Absorption Fields

Nearly half of Indiana's population lives in residences having private waste disposal systems. As is common in many areas of Indiana, septic tanks and septic tank absorption fields are utilized for wastewater treatment around Cook, Holem, Millpond, and Kreighbaum Lakes and other lakes (Myers, Lawrence, and Thomas Lakes) in the Four Lakes watershed. This type of wastewater treatment system relies on the septic tank for primary treatment to remove solids and the soil for secondary treatment to reduce the remaining pollutants in the effluent to levels that protect surface and groundwater from contamination. The soil's ability to sequester and degrade pollutants in septic tank effluent will ultimately determine how well surface and groundwater is protected.

A variety of factors can affect a soil's ability to function as a septic absorption field. Seven soil characteristics are currently used to determine soil suitability for on-site sewage disposal systems: position in the landscape, slope, soil texture, soil structure, soil consistency, depth to limiting layers, and depth to seasonal high water table (Thomas, 1996). The ability of soil to treat effluent (waste discharge) depends on four factors: the amount of accessible soil particle surface area, the chemical properties of the soil particle's surfaces, soil conditions like temperature, moisture, and oxygen content, and the types of pollutants present in the effluent (Cogger, 1989).

The amount of accessible soil particle surface area depends both on particle size and porosity. Because they are smaller, clay particles have a greater surface area per unit volume than silt or sand and, therefore, a greater potential for chemical activity. However, soil surfaces only play a role if wastewater can contact them. Soils of high clay content or soils that have been compacted often have few pores that can be penetrated by water and are not suitable for septic systems because they are too impermeable. Additionally, some clays swell and expand on contact with water closing the larger pores in the profile. On the other hand, very coarse soils may not offer satisfactory effluent treatment either because the water can travel rapidly through the soil profile. Soils located on sloped land also may have difficulty in treating wastewater due to reduced contact time.

Chemical properties of the soil surfaces are also important for wastewater treatment. For example, clay materials have imperfections in their crystal structure which gives them a negative charge along their surfaces. Due to their negative charge, they can bond cations of positive charge to their surfaces. However, many pollutants in wastewater are also negatively charged and are not attracted to the clays. Clays can help remove and inactivate bacteria, viruses, and some organic compounds.

Environmental soil conditions influence the microorganism community which ultimately carries out the treatment of wastewater. Factors like temperature, moisture, and oxygen availability influence microbial action. Excess water or ponding saturates soil pores and slows oxygen transfer. The soil may become anaerobic if oxygen is depleted. Decomposition process (and therefore, effluent treatment) becomes less efficient, slower, and less complete if oxygen is not available.

Many of the nutrients and pollutants of concern are removed safely if a septic system is sited correctly. Most soils have a large capacity to hold phosphate. On the other hand, nitrate (the end product of nitrogen metabolism in a properly functioning septic system) is very soluble in soil solution and is often leached to the groundwater. Care must be taken in siting the system to avoid well contamination. Nearly all organic matter in wastewater is biodegradable as long as oxygen is present. Pathogens can be both retained and inactivated within the soil as long as conditions are right. Bacteria and viruses are much smaller than other pathogenic organisms associated with wastewater and, therefore, have a much greater potential for movement through the soil. Clay minerals and other soil components may adsorb bacteria and viruses, but retention is not necessarily permanent. During storm flows, bacteria and viruses may become resuspended in the soil solution and transported throughout the soil profile. Inactivation and destruction of pathogens occurs more rapidly in soils containing oxygen because sewage organisms compete poorly with the natural soil microorganisms, which are obligate aerobes requiring oxygen for life. Sewage organisms live longer under anaerobic conditions without oxygen and at lower soil temperatures because natural soil microbial activity is reduced.

Taking into account the various factors described above, the NRCS has ranked each soil series in the Four Lakes watershed in terms of its limitations for use as a septic tank absorption field.

Each soil series is placed in one of three categories: slightly limited, moderately limited, or severely limited. Use of septic absorption fields in moderately or severely limited soils generally requires special design, planning, and/or maintenance to overcome the limitations and ensure proper function. Figure 6 displays the septic tank suitability of soils throughout the Four Lakes watershed. Nearly all of Cook Lake's shoreline is bordered by soils that are severely limited for use as septic tank absorption fields. Only the northwestern shoreline and a small area along the northern shoreline are moderately limited. Conversely, only Holem Lake's northern shoreline is severely limited for septic treatment, while the southern shoreline is moderately limited. Like Cook Lake, nearly the all of Kreighbaum and Millpond Lakes' shorelines are severely limited. Small portions of Millpond Lake's southern and western shorelines are slightly to moderately limited for use as septic tank absorption fields. Overall, soils severely limited for use a septic tank absorption fields cover nearly 44% of the watershed (1,271 acres or 514 ha), while moderately limited soils cover an additional 38% of the watershed (1,094 acres or 442.7 ha). Less than 5% of the Four Lakes watershed is covered by soils that are only slightly limited for use as septic tank absorption fields.

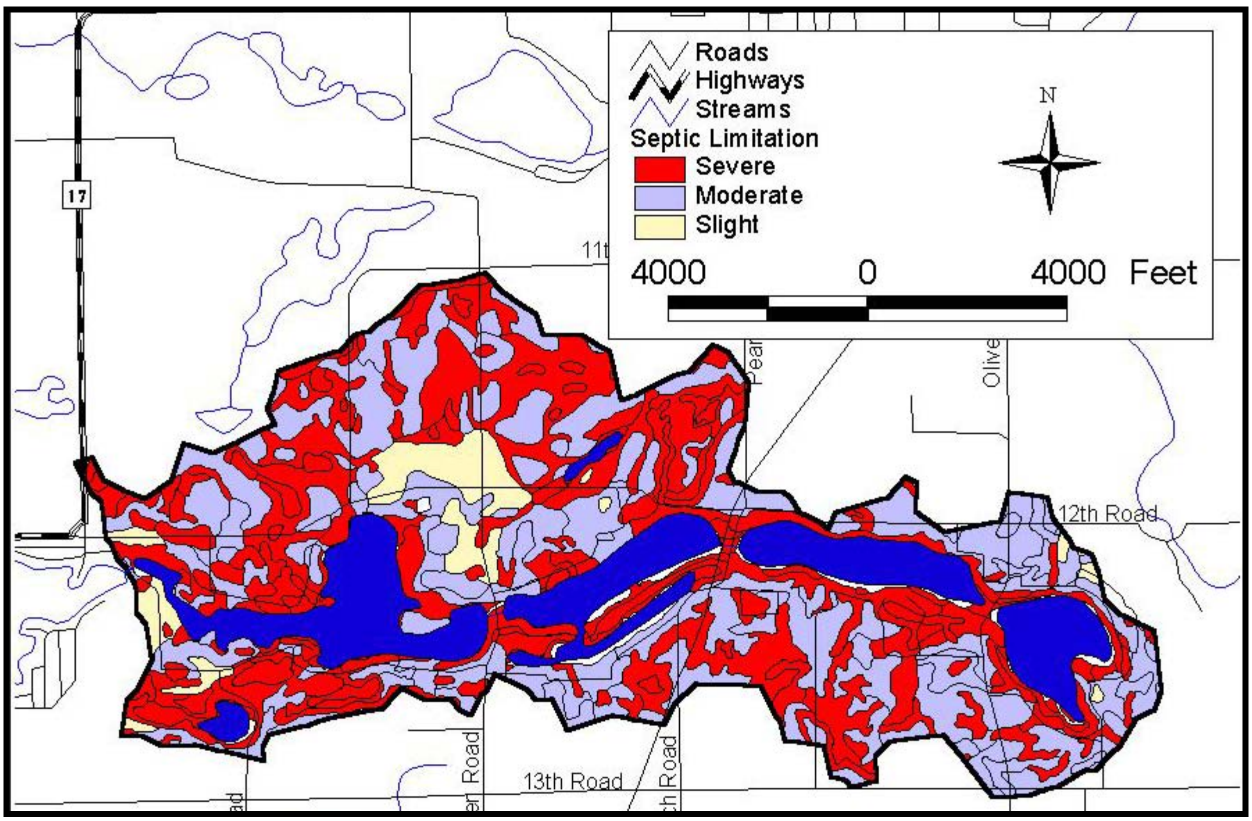

Figure 6. Soil septic tank suitability within the Four Lakes watershed.
Source: See Appendix A. Scale: 1"= 4,000'.

While all septic system use in the Four Lakes watershed has the potential to impact the water quality of Cook, Holem, Millpond, and Kreighbaum Lakes, the ability of the soil immediately adjacent to each of the Four Lakes to treat septic effluent has a more direct effect on the lakes' water quality than the ability of the soil in other areas of the watershed. For example, the soils directly adjacent to the Cook Lake have a more direct effect on Cook Lake than the soils in other areas of the watershed. Likewise, the soils directly adjacent to Kreighbaum and Millpond Lakes have a more direct effect on the water quality within Kreighbaum and Millpond Lakes. Therefore, the following discussion focuses on the soils adjacent to Cook, Holem, Kreighbaum, and Millpond Lakes, respectively.

Cook and Holem Lakes

Figure 7 shows the soil units surrounding Cook and Holem Lakes, while Table 4 summarizes the soils' suitability for use as septic tank absorption fields. Following Table 4 is a short description of the soils listed in the table.

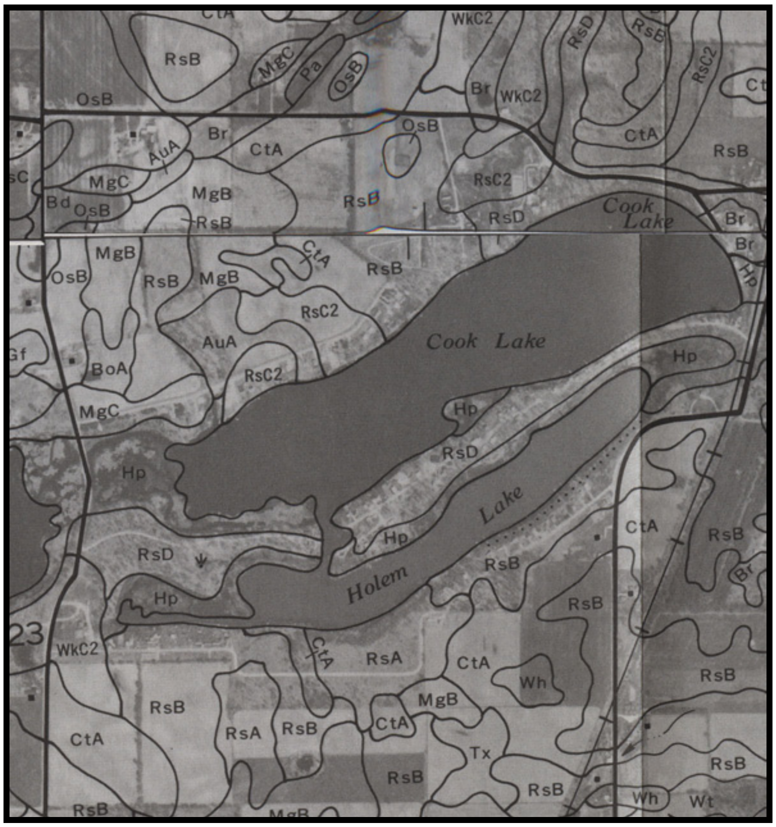

Figure 7. Soil series bordering Cook and Holem Lakes.
Source: Smallwood, 1980. Scale: 1"=1,667'.

Table 4. Soil types adjacent to Cook and Holem Lakes and their suitability to serve as a septic tank absorption field.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
AuA	Aubbeenaubbee sandy loam	1-3 ft.	Severe: wetness
Br	Brookston loam	+0.5-1.0 ft.	Severe: ponding
CtA	Crosier loam	1-3 ft.	Severe: percs slowly, wetness
Hp	Houghton muck, ponded	+2.0-0.5 ft.	Severe: ponding, percs slowly
RsA-RsB	Riddles sandy loam	>6 ft.	Moderate: percs slowly
RsC2	Riddles sandy loam	>6 ft.	Moderate: percs slowly, slope
RsD	Riddles sandy loam	>6 ft.	Severe: slope

A seasonal high water table limits the treatment capacity of Aubbennaubbee sandy loam (AuA) soils. These soils are typically found on poorly drained, broad, flat areas where water remains ponded throughout the winter and spring. The water table is near, though never above, the surface as is the case with the Houghton muck soils. These soils are rated as severely compromised for septic systems because of wetness and the moderate to rapid permeability of the subsoil.

Brookston loam (Br) soils are very poorly drained soils that are frequently ponded. The ponding severely limits these soils for use as septic tank absorption fields. The water table is typically near the soil surface in winter and spring months. Proper septic system function in these soils is severely limited because the soil tends to remain wet and does not readily absorb liquid waste.

Crosier loam (CtA) soils are very poorly drained soils. They are found in slight depressions on broad outwash plains and terraces, along small drainageways, and in depressions on till plains, terraces, and outwash plains. Because of the ponding, these soils are unsuitable for septic tank absorption fields.

Houghton muck, ponded (Hp) is a nearly level, poorly drained soil. This soil is generally covered by shallow water most of the year, and in some years, it is continually covered. Smallwood (1980) characterizes this soil as optimal for wildlife habitat by poor for all other uses. These soils are absolutely unsuitable for sanitary facilities due to ponding and permeability issues. Because these soils generally occupy some of the lowest points on the landscape, pumping systems are necessary for adequate drainage.

Riddles sandy loam (RsA-RsB) soils are well-drained soils that are moderately limited for septic system use due to moderate permeability. Enlarged septic fields built within this soil type will better absorb effluent. The Riddles sandy loam (RsC2) soils are also moderately limited for septic suitability. Moderate slopes and permeability may limit the ability of the field to absorb the effluent. However, steep slopes limit the use of Riddles sandy loam (RsD) soils if the slope is greater than 12%.

As shown in Table 4, all of the soils that border Cook and Holem Lakes are moderately to severely limited for use as a septic tank absorption field. No residences currently exist along the northeastern shoreline of Cook Lake, below the ridge along the northern shoreline of Holem Lake, or within the area between Queen Road and the western shorelines of Cook and Holem Lakes. Soils in these areas are mapped as Houghton muck (Hp) and Riddles sandy loam (RsD). If these portions of the shoreline become developed, then residents should take extra care in septic leach field placement and sizing. However, because these portions of Cook and Holem Lakes' shorelines remain undeveloped, septic system leaching from these portions of the lakes does not impact water quality in Cook and Holem Lakes at this time. Currently, most of the residences exist along the northwestern shoreline of Cook Lake, on the ridge between Cook and Holem Lakes, and along the southern shoreline of Holem Lake where soils are mapped as Riddles sandy loam (RsA-RsB, RsC2, RsD) and Aubbennaubbee sandy loam (AuA). Septic fields placed in these soils typically require larger leach fields to overcome the ponding and permeability issues associated with these soils. Unfortunately, enlarging the existing septic leach fields or creating new leach fields, if sufficient room exists, may be too costly. At a minimum, residents in existing homes should take steps to properly care for their septic tanks, avoiding the disposal of household chemicals that may kill soil bacteria, and implementing water conservation measures to alleviate strains on the system.

Kreighbaum and Millpond Lakes

Figure 8 shows the soil units surrounding Kreighbaum and Millpond Lakes, while Table 5 summarizes the soils' suitability for use as septic tank absorption fields. Following Table 5 is a short description of the soils listed in the table.

Figure 8. Soil series bordering Kreighbaum and Millpond Lakes.
Source: Smallwood, 1980. Scale: 1"=1,667'.

Table 5. Soil types adjacent to Kreighbaum and Millpond Lakes and their suitability to serve as a septic tank absorption field.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
Hp	Houghton muck, ponded	+2.0-0.5 ft.	Severe: ponding, percs slowly
MgB	Metea loamy fine sand	>6 ft.	Severe: percs slowly
MgC	Metea loamy fine sand	>6 ft.	Severe: percs slowly, slope
OsC	Oshtemo loamy sand	>6 ft.	Moderate: slope
OwA	Owosso sandy loam	>6 ft.	Moderate: percs slowly
PsD	Plainfield sand	>6 ft.	Severe: slope, poor filter
Re	Rensselaer loam	+0.5-1.0 ft.	Severe: ponding, percs slowly
RsA-RsB	Riddles sandy loam	>6 ft.	Moderate: percs slowly
RsC2	Riddles sandy loam	>6 ft.	Moderate: percs slowly, slope
RsD	Riddles sandy loam	>6 ft.	Severe: slope
Wa	Wallkill loam	+0.5-0.5 ft.	Severe: ponding
WkB	Wawasee sandy loam	>6 ft.	Slight
WkC2	Wawasee sandy loam	>6 ft.	Moderate: slope
WmD3	Wawasee sandy clay loam	>6 ft.	Severe: slope

All of the soils that border Kreighbaum and Millpond Lakes are moderately to severely limited for use as septic tank absorption fields except Wawasee sandy loam (WkB), which is only slightly limited.

Rensselaer loam (Re) and Wallkill loam (Wa) soils are very poorly drained soils which are frequently ponded. The ponding severely limits these soils for use as septic tank absorption fields. The water table is typically near the soil surface in winter and spring months. Proper septic system function in these soils is severely limited because the soil tends to remain wet and does not readily absorb liquid waste.

Houghton muck, ponded (Hp) is a nearly level, poorly drained soil. This soil is generally covered by shallow water most of the year, and in some years, it is continually covered. Fortunately, most of the septic systems in the Four Lakes watershed are not located in these soils. Smallwood (1980) characterizes this soil as optimal for wildlife habitat but poor for all other uses. These soils are absolutely unsuitable for sanitary facilities due to ponding and permeability issues. Because these soils generally occupy some of the lowest points on the landscape, pumping systems are necessary for adequate drainage.

Metea loamy fine sand (MgB-MgC) soils are found on gently to strongly sloping hillsides of uplands. Fluid movement through this soil type is moderately slow. The slow permeability and wetness generally inhibit complete waste treatment. The slow permeability of Metea soils is a result of soil formation and aging processes. When Metea loamy fine sand soils are located along steep slopes, slope can also pose problems for proper septic field function.

Seepage of septic effluent due to soil slope limits four soils. Oshtemo loamy sand (OsC) and Wawasee sandy loam (WkC2) are moderately limited due to slope, while slope severely limits Riddles sandy loam (RsD) and Wawasee sandy clay loam (WmD3) soils. Building a septic system on the ridge top or level contours or using an enlarged absorption field allows these soils to be used for septic treatment.

Owosso sandy loam (OwA) and Riddles sandy loam (RsA-RsB) soils are well-drained soils that are moderately limited for septic system use due to moderate permeability. Enlarged septic fields built within this soil type will better absorb effluent. The Riddles sandy loam (RsC2) soils are also moderately limited for septic suitability. Moderate slopes and permeability may limit the ability of leachate fields built in these soils from absorption effluent.

Plainfield sand (PsD) soils are well-drained soils found on moderately to strongly sloping hillsides. Permeability rates are rapid to moderately rapid in the subsoil and very rapid in the underlying material. Due to the rapid permeability of these soils, they do not provide adequate filtering capability when used as septic tank absorption fields and may result in pollution of the ground water.

As shown in Table 5, all of the soils surrounding Kreighbaum and Millpond Lakes are moderately to severely limited in their use as a septic tank absorption field with the exception of Wawasee sandy loam (WkB) soils. Currently, most of the residences are located along the northwestern and southeastern shorelines of Millpond Lake where soils are mapped as Wallkill loam (Wa), Rensselaer loam (Re), Plainfield sand (PsD), Metea loamy fine sand (MgC), and Wawasee sandy loam (WkC2). Residences are generally located along the western, northern, and northeastern shorelines of Kreighbaum Lake where soils are mapped as Riddles sandy loam (RsB-RsC2), Oshtemo loamy sand (OsC), and Metea loamy fine sand (MgC). Septic fields placed in these soils typically require larger leach fields to overcome the ponding and slow permeability of most of these soils. Unfortunately, enlarging the existing septic leach fields or creating new leach fields, if sufficient room, exists may be too costly. At a minimum, residents in existing homes should take steps to properly care for their septic systems such as pumping their septic tanks, avoiding the disposal of household chemicals that may kill soil bacteria, and implementing water conservation measures to alleviate strain on the system.

2.5 Natural History

Geographic location, climate, topography, geology, soils, and other factors play a role in shaping the native floral (plant) and faunal (animal) communities in a particular area. Various ecologists (Deam, 1921; Petty and Jackson, 1966; Homoya et al., 1985; Omernik and Gallant, 1988) have divided Indiana into several natural regions or ecoregions, each with similar geographic history, climate, topography, and soils. Because the groupings are based on factors that ultimately influence the type of vegetation present in an area, these natural areas or ecoregions tend to support characteristic native floral and faunal communities. Under many of these classification systems, the Four Lakes watershed lies at or near the transition between two or more regions. For example, the watershed lies at the western boundary separating Homoya's Northern Lakes Natural Area to the east from the Grand Prairie Natural Area to the west. Similarly, the Four Lakes watershed lies in Omernik and Gallant's Eastern Corn Belt Plains Ecoregion (ECBP) immediately south of the point where the ECBP Ecoregion meets the Central Corn Belt Plains and Southern Michigan/Northern Indiana Till Plains Ecoregions. As a result, the native floral community of the Four Lakes watershed likely consisted of components of neighboring natural areas and ecoregions in addition to components characteristic of the natural area and ecoregion in which it is mapped.

Homoya et. al (1985) noted that prior to European settlement, the region was a mixture of numerous natural community types including bog, fen, marsh, prairie, sedge meadow, swamp, seep spring, lake and deciduous forest. The dry to dry-mesic uplands were likely forested with red oak, white oak, black oak, shagbark hickory, and pignut hickory. More mesic areas probably harbored beech, sugar maple, black maple, and tulip poplar with sycamore, American elm, red elm, green ash, silver maple, red maple, cottonwood, hackberry, and honey locust dominating the floodplain forests. Historical records support the observation that prior to European settlement of West Township dense oak-hickory forests covered the Four Lakes watershed (Historic Landmarks Foundation, 1990). Chamberlain (1849) described the area as being heavily timbered with oak openings or barrens covered by wet or dry prairies and lakes. White oak was the dominant component of the heavily timbered areas with shagbark hickory, maple, beech, elm, walnut, butternut, and red and black oak as subdominants (McDonald, 1908; Petty and Jackson, 1966; Omernik and Gallant, 1988). Red and black oak, buroak, and hickory as well as sugar maple and beech also grew in the watershed but likely not to the extent observed throughout northern Indiana (McDonald, 1908). Petty and Jackson (1966) list pussy toes, common cinquefoil, wild licorice, tick clover, blue phlox, waterleaf, bloodroot, Joe-pye-weed, woodland asters, woodland goldenrods, wild geranium, and bellwort as common components of the forest understory in the watershed’s region.

Wet habitat (ponds, marshes, and swamps) intermingled with the upland habitat throughout the Four Lakes watershed. The hydric soils map and an 1876 map of Marshall County (Baskins, Forster, and Company, 1876) indicate that wetland habitat existed throughout much of the Four Lakes watershed including portions of Cook, Holem, Kreighbaum, and Millpond Lakes. These wet habitats supported very different vegetative communities than the drier portions of the landscape. Swamp loosestrife, cattails, soft stem bulrush, marsh fern, marsh cinquefoil, pickerel weed, arrow arum, and sedges dominated the marsh habitat throughout the watershed. Swamp habitat likely covered most or all of the shallow depressions in the watershed. Typical dominant swamp species in the area included red and silver maple, green and black ash, and American elm (Homoya, 1985). Smallwood (1980) adds swamp white oak to the list of dominants in swamp habitat throughout the county.

The first grist mill in Marshall County altered the natural landscape of the Four Lakes watershed. The lakes were irreversibly altered by the building of an iron forge and grist mill. A dam at what is now Queen Road created Zehner Mill Pond. For the next 40 years, the grist mill and associated town of Sligo flourished. More than 40 individuals dug iron ore from the surround marshes washing the ore in the lakes and streams and using the power from Forge Creek (now Harry Cool Ditch) to run the smelter (Faulkner, 1961). The town, mill, and smelter were gradually abandoned and in 1922 the area was cleared and the mill removed (Swindell, 1923). The shoreline of the remnant mill pond has since been developed and is now Millpond Lake.

2.6 Land Use

Just as soils, climate, and geology shape the native communities within the watershed, how the land in a watershed is used can impact the water quality of a waterbody. Different land uses have the potential to contribute different amounts of nutrients, sediment, and toxins to receiving water bodies. For example, Reckhow and Simpson (1980) compiled phosphorus export coefficients (amount of phosphorus lost per unit of land area) for various land uses by examining the rate at which phosphorus loss occurred on various types of land. (The *Phosphorus Modeling Section* of the report contains more detailed information on this work and its impact on the Four Lakes and their watershed.) Several researchers have also examined the impact of specific urban and suburban land uses on water quality (Bannerman et. al, 1992; Steuer et al., 1997; Waschbusch et al., 2000). Bannerman et al. (1992) and Steuer et al. (1997) found high mean phosphorus concentrations in runoff from residential lawns (2.33 to 2.67 mg/L) and residential streets (0.14 to 1.31 mg/L). These concentrations are well above the threshold at which lakes might begin to experience algae blooms. (Lakes with total phosphorus concentrations greater than 0.03 mg/L will likely experience algae blooms.) Finally, the Center for Watershed Protection has estimated the association of increased levels of impervious surface in a watershed with increased delivery of phosphorus to receiving waterbodies (Caraco and Brown, 2001). Land use directly affects the amount of impervious surface in a watershed. Because of the effect watershed land use has on water quality of the receiving lakes, mapping and understanding a watershed's land use is critical in directing water quality improvement efforts.

Four Lakes Watershed

Table 6 and Figure 9 present current land use information for the Four Lakes watershed. (Land use data from the U.S. Geological Survey (USGS) forms the basis of Figure 9. Corrections to the Indiana Land Cover Data Set were made based on 2003 aerial photographs.) Like many Indiana watersheds, agricultural land use dominates the Four Lakes watershed accounting for approximately 52% of the watershed. Row crop agriculture makes up the greatest percentage of agricultural land use at 37% while pastures or hay vegetate another 15%. Most of the agricultural land in the Four Lakes watershed and throughout Marshall County (USDA, 2002) is used for growing corn and soybeans. County-wide tillage transect data for Marshall County provides an estimate for the portion of cropland in conservation tillage for the Four Lakes watershed. In Marshall County, corn producers utilize no-till methods on 11% of corn fields and some form of reduced tillage on 66% of corn fields. The percentage of corn fields on which no-till methods were used in Marshall County was below the statewide median percentage. Marshall County soybean producers used no-till methods on 36% of soybean fields and some form of reduced tillage on 59% of soybean fields in production (IDNR, 2004a).

Table 6. Detailed land use in the Four Lakes watershed.

Land Use	Area (acres)	Area (hectares)	% of Watershed
Row Crops	1064.8	431.1	37.2%
Deciduous Forest	518.8	210.0	18.1%
Pasture/Hay	440.6	178.4	15.4%
Open Water	413.8	167.5	14.4%
Low Intensity Residential	273.3	110.7	9.5%
Emergent Herbaceous Wetlands	78.7	31.9	2.7%
Woody Wetlands	44.7	18.1	1.6%
Evergreen Forest	21.0	8.5	0.7%
High Intensity Residential	3.6	1.4	0.1%
High Intensity Commercial	3.5	1.4	0.1%
Mixed Forest	1.5	0.6	0.1%
Entire Watershed	**2864.2**	**1159.6**	**100.0%**

Land uses other than agriculture account for the remaining 47% of the watershed. Natural landscapes including forests and wetland account for approximately 23% of the watershed. Large tracts of natural areas cover the northeastern, western, and southern shorelines of Millpond Lake and the southeastern shoreline of Kreighbaum Lake and border portions of Holem Lake's southern and western shorelines. Additional forested tracts are located south of Myers Lake, north of Cook Lake, and west of Lawrence Lake (Figure 9). Open water, including Millpond, Kreighbaum, Cook, Holem, Myers, Lawrence, and Thomas Lakes, accounts for another 14% of the watershed.

The remaining 10% of the watershed is occupied by residential land, most of which lies directly adjacent to the six lakes in the chain. According to the USGS's definition, low intensity residential areas consist largely of single-family homes where impervious surfaces (driveways, sidewalks, roads, rooftops, etc.) cover approximately 30 to 80% of the area. Using this definition and assuming that impervious surfaces cover approximately 50% of the residential land (an estimate on the low side of the range), impervious surfaces cover approximately 5% of the watershed. This estimate of impervious surface coverage is below the threshold at which the Center for Watershed Protection has found an associated decline in water quality.

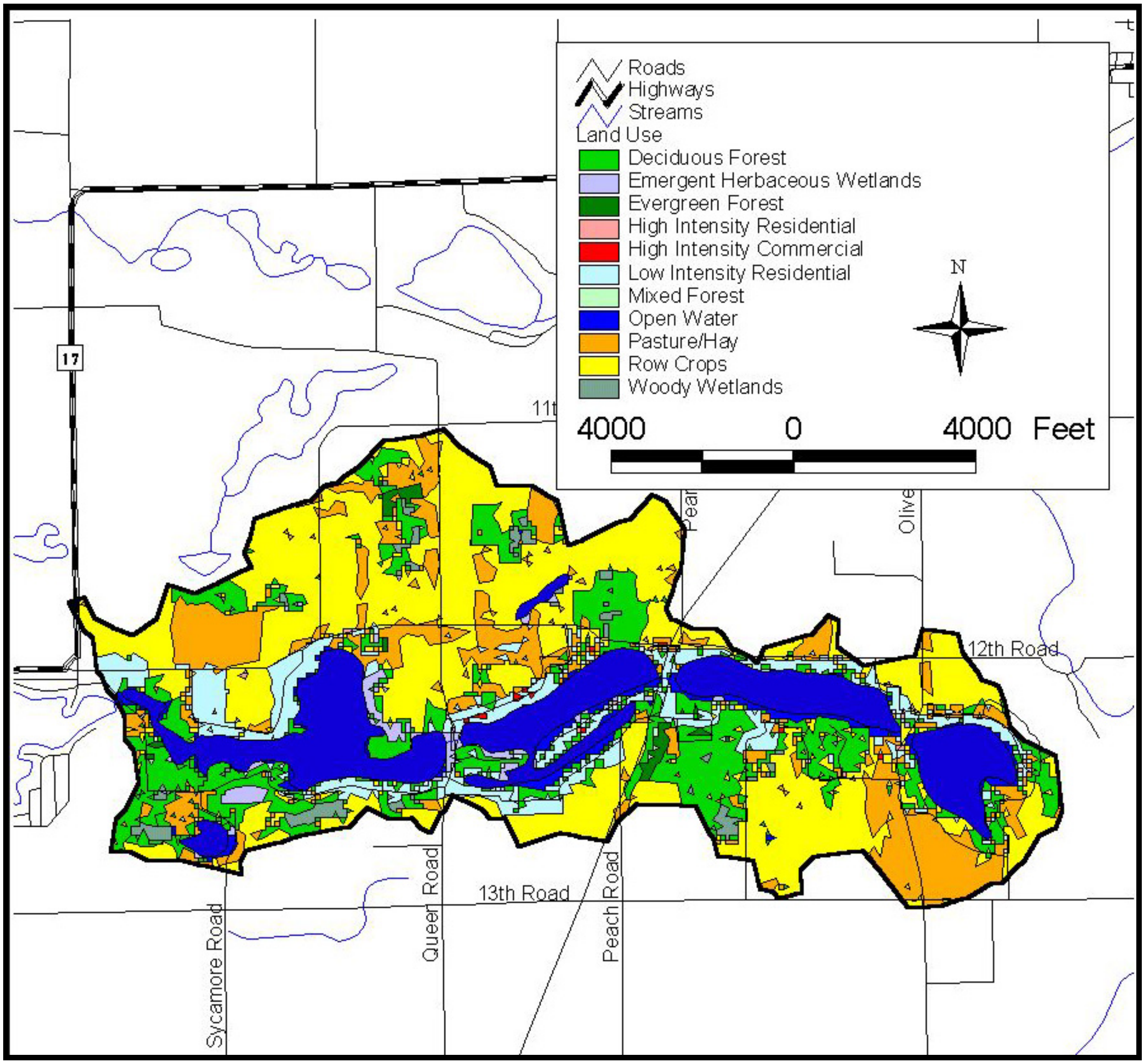

Figure 9. Land use in the Four Lakes watershed.
Source: See Appendix A. Scale: 1”=4,000’.

Cook Lake
Land use within Cook Lake’s immediate watershed parallels that of the entire Four Lakes watershed. Agricultural land use also dominates the Cook Lake watershed (Table 7). Row crop agriculture covers approximately 38% of the watershed, while pasture or hay covers an additional 18%. Land use other than agricultural accounts for 44% of the watershed. Natural landscapes including forested areas and wetlands account for approximately 17% and 3% of the watershed, respectively. Open water in the form of Cook, Myers, and Lawrence Lakes covers another 15% of the watershed. Commercial and residential land uses cover the remaining 8% of the watershed and are typically located along Cook Lake’s shoreline.

Table 7. Land use within the Cook Lake watershed.

	Area (acres)	Area (ha)	Percent of Watershed
Row Crops	577.5	233.8	38.0%
Pasture/Hay	266.5	107.9	17.5%
Deciduous Forest	258.1	104.5	17.0%
Open Water	235.6	95.4	15.5%
Low Intensity Residential	123.7	50.1	8.1%
Emergent Herbaceous Wetlands	29.0	11.7	1.9%
Woody Wetlands	20.3	8.2	1.3%
High Intensity Commercial	3.4	1.4	0.2%
Evergreen Forest	3.3	1.3	0.2%
High Intensity Residential	2.7	1.1	0.2%
Mixed Forest	0.1	0.1	<0.1%
Cook Lake Watershed	**1,520.3**	**615.5**	**100.0%**

Holem Lake
Agricultural land use also dominates Holem Lake's immediate watershed landscape (Table 8). Row crop agriculture covers approximately 37% of the watershed, while pasture or hay covers an additional 4% of the watershed. Natural landscapes including forested areas and wetlands account for approximately 24% and 3%, respectively. Most of these natural areas are contiguous with Holem Lake. Open water in the form of Holem Lake covers 12% of the watershed. An additional 20% of the watershed is used for residential uses.

Table 8. Land use within the Holem Lake watershed.

	Area (acres)	Area (ha)	Percent of Watershed
Row Crops	80.6	32.6	37.2%
Low Intensity Residential	42.7	17.3	19.7%
Deciduous Forest	42.4	17.2	19.5%
Open Water	27.0	10.9	12.4%
Evergreen Forest	8.1	3.3	3.7%
Pasture/Hay	7.9	3.2	3.6%
Emergent Herbaceous Wetlands	7.2	2.9	3.3%
Mixed Forest	1.0	0.4	0.4%
High Intensity Commercial	0.1	0.1	<0.1%
Holem Lake Watershed	**217.0**	**87.8**	**100.0%**

Kreighbaum Lake
Land use within Kreighbaum Lake's immediate watershed follows the same pattern as that observed throughout the rest of the Four Lakes watershed. Agricultural land use dominates the Kreighbaum Lake watershed (Table 9). Row crop agriculture covers approximately 51% of the watershed, while pasture or hay covers an additional 17%. Land use other than agricultural accounts for 32% of the watershed. Natural landscapes including forested areas and wetlands account for approximately 14% and 2% of the watershed, respectively. Open water in the form

of Kreighbaum Lake covers another 8% of the watershed. Residential land uses cover the remaining 6% of the watershed and are primarily located along the northern shoreline of Kreighbaum Lake.

Table 9. Land use within the Kreighbaum Lake watershed.

	Area (acres)	Area (ha)	Percent of Watershed
Row Crops	237.5	96.1	51.1%
Pasture/Hay	78.0	31.6	16.8%
Deciduous Forest	59.9	24.3	12.9%
Open Water	37.0	15.0	8.0%
Low Intensity Residential	29.2	11.8	6.3%
Emergent Herbaceous Wetlands	9.1	3.7	2.0%
Evergreen Forest	7.0	2.8	1.5%
Woody Wetlands	6.5	2.6	1.4%
High Intensity Residential	0.4	0.2	0.1%
Kreighbaum Lake Watershed	**464.4**	**188.0**	**100.0%**

2.7 Wetlands

Because wetlands perform a variety of functions in a healthy ecosystem, they deserve special attention when examining watersheds. Functioning wetlands filter sediments and nutrients from runoff, store water for future release, alleviate flooding, provide an opportunity for groundwater recharge or discharge, and serve as nursery and forage habitat for various fish and wildlife species. By performing these roles, healthy, functioning wetlands often improve water quality and the biological health of streams and lakes located downstream of the wetlands.

The United States Fish and Wildlife Service's (USFWS) National Wetland Inventory (NWI) Map (Figure 10) shows that wetlands and open water cover approximately 21.1% of the Four Lakes watershed. In total, wetlands cover approximately 8.1% of the watershed, while open water covers an additional 13% of the watershed. (Table 10 presents the acreage of wetlands by type according to the National Wetland Inventory.) Large, contiguous tracts of wetland habitat border the southern shoreline of Lawrence Lake and the northern and southern shorelines of Millpond Lake. The largest wetland tract connects the east ends of Cook and Holem Lakes with the northern shoreline of Millpond Lake and the eastern shoreline of Kreighbaum Lake. Additional wetland habitat covers much of the watershed south of Millpond and Kreighbaum Lakes and is scattered throughout the northern portion of the watershed.

Table 10. Acreage and classification of wetland habitat in the Four Lakes watershed.

Wetland Type	Area (acres)	Area (hectares)	Percent of Watershed
Lake	373.2	151.1	13.0%
Emergent Herbaceous	133.4	54.0	4.7%
Forested	78.8	31.9	2.8%
Scrubland	2.2	0.9	0.1%
Submerged Herbaceous	9.5	3.8	0.3%
Ponds	7.8	3.2	0.3%
Entire Watershed	**604.8**	**245.0**	**21.1%**

The USFWS NWI data differs in its estimate of wetland habitat acreage in the watershed from the USGS data presented in Table 6 and Figure 9. The USGS Land Cover Data Set suggests that wetlands cover 4.3% of the Four Lakes watershed and open water covers an additional 14.4% of the watershed (Table 10). The main differences between the two data sets are the inclusion of forest land as wetlands by the USFWS and the acreage of emergent wetland. The USFWS reports approximately 79 acres (32 ha) of forested wetland, which is likely included as part of the forested cover by the USGS. Likewise, the USFWS indicates that approximately 133 acres (54 ha) of emergent wetland habitat exists in the Four Lakes watershed compared to less than 80 acres (32.4 ha) reported by the USGS. The differences in reported wetland acreage in the Four Lakes watershed reflect the differences in project goals and methodology used by the different agencies to collect land use data.

The IDNR estimates that approximately 85% of the state's wetlands have been filled (IDNR, 1996). The greatest loss has occurred in the northern counties of the state such as Marshall County. The last glacial retreat in these northern counties left level landscapes dotted with wetland and lake complexes. Development of the land in these counties for agricultural purposes altered much of the natural hydrology, eliminating many of the wetlands.

To estimate the historical coverage of wetlands in the Four Lakes watershed, hydric soils in the watershed were mapped (Figure 11). (As noted for the potentially highly eroded soils map, this map is based on the Natural Resources Conservation Service criteria for hydric soils and is not field checked.) Because hydric soils developed under wet conditions, they are a good indicator of the historical presence of wetlands. Comparing the total acreage of wetland (hydric) soils in the watershed (1,146.5 acres or 464.3 ha) to the acreage of existing wetlands (231.7 acres or 245.0 ha) suggests that nearly 20% of the original wetland acreage exists today. The most significant wetland losses have occurred north of 12th Road and south of Myers Lake. These losses become obvious by comparing Figures 10 and 11.

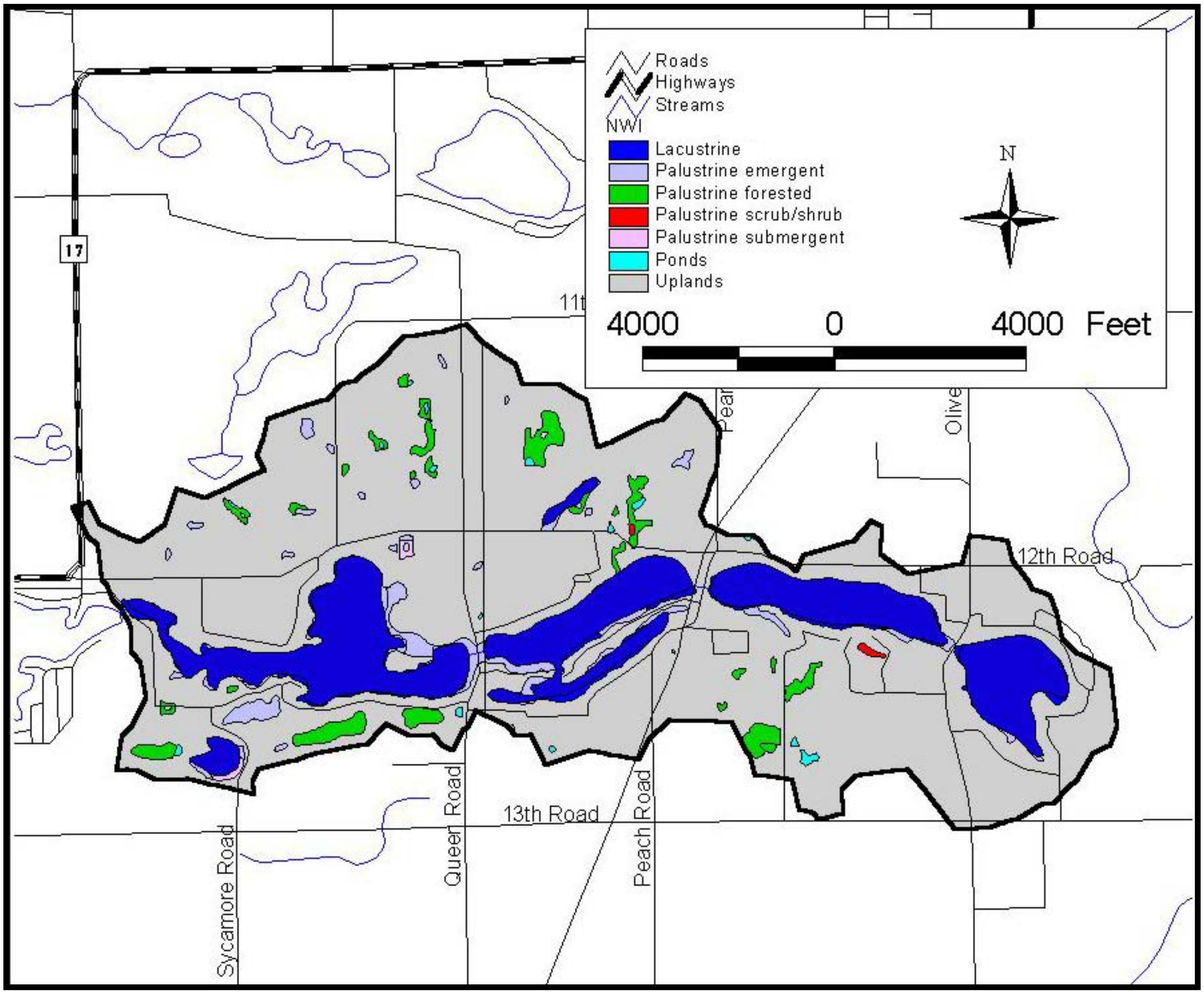

Figure 10. Wetlands in the Four Lakes watershed.
Source: See Appendix A. Scale: 1”=4,000’.

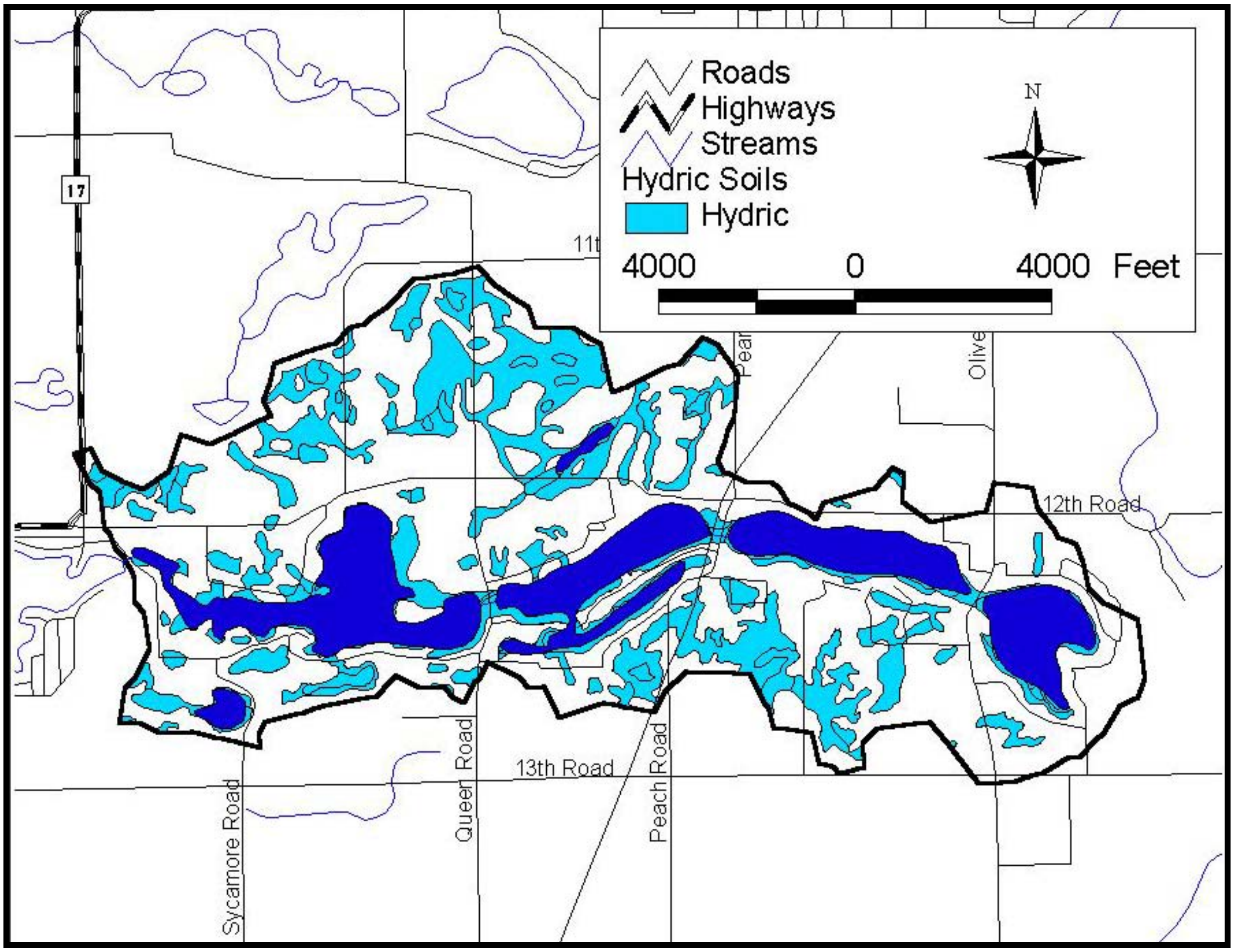

Figure 11. Hydric soils in the Four Lakes watershed.
Source: See Appendix A. Scale: 1"=4,000'.

2.8 Natural Communities and Endangered, Threatened, and Rare Species

The Indiana Natural Heritage Data Center database provides information on the presence of endangered, threatened, or rare species; high quality natural communities; and natural areas in Indiana. The Indiana Department of Natural Resources developed the database to assist in documenting the presence of special species and significant natural areas and to serve as a tool for setting management priorities in areas where special species or habitats exist. The database relies on observations from individuals rather than systematic field surveys by the IDNR. Because of this, it does not document every occurrence of special species or habitat. At the same time, the listing of a species or natural area does not guarantee that the listed species is present or that the listed area is in pristine condition. To assist users, the database includes the date that the species or special habitat was last observed in a specific location.

Appendix B presents the results from the database search for the Four Lakes watershed. (For additional reference, Appendix C provides a listing of endangered, threatened, and rare species (ETR) documented in Marshall County.) The database documents relatively few endangered, threatened, or rare species; high quality natural communities; or natural areas in the Four Lakes watershed. The habitat within the watershed supports or at least historically supported one state endangered animal species, the American badger (*Taxidea taxus*, 1988), and two species of special concern including the pointed campeloma (*Campeloma decisum*, 1988), which is a snail species, and cisco (*Coregonus artedi*, 1988 and 1994) or lake heron, a fish species in the trout/salmon family. The database document the sightings of the American badger near the northern boundary of the watershed immediately south of the Menominee Wetland Conservation Area. The database indicates that the two species of special concern were found within or adjacent to Lawrence Lake. The last documented sightings of pointed campeloma occurred in Myers and Lawrence Lakes in 1988, while cisco were last observed in Myers Lake in 1988 and in Lawrence Lake in 1994. Based on field surveys conducted by biologists, JFNew (2000) concluded that is was unlikely that either cisco or pointed campeloma still exist within Myers or Lawrence Lakes. The database also notes the presence of one significant natural community, a fen located between Millpond and Thomas Lakes in the southwestern corner of the Four Lakes watershed.

3.0 LAKE ASSESSMENT

3.1 Morphology and Shoreline Development

3.1.1 Cook Lake

Figure 12 presents Cook Lake's morphology. Cook Lake is approximately 93 acres (37.6 ha) in size and contains a volume of 1,647 acre-feet (2,031,114.6 m^3; Table 11). Cook Lake possesses a long narrow basin which lies along the northeast-southwest ordinance. The basin measures approximately 8,570 feet (2,612 m) in length and varies from 1,160 to 1,770 feet (353.6 to 539.5 m) in width. Cook Lake contains three distinct deep holes which lie in the center of the lake basin. The lake extends to a maximum depth of 52 feet (15.8 m) in the southwestern hole. The center and northeastern holes are slightly shallower with depths of 45 feet (13.7 m) and 46 feet (14.0 m), respectively. Water as shallow as 35 feet (10.7 m) separates the three deep holes. Cook Lake possesses large expanses of shallow water. According to its depth-area curve (Figure 13), approximately 44 acres (17.8 ha or 47%) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 56% of the lake (52 acres or 21.0 ha) is less than 20 feet (6.1 m) deep. Figure 14 shows that the lake's volume gradually increases to a depth of 35 feet (10.7 m) where the curve gradually becomes steeper with each 5-foot (1.5-m) interval increase in depth. The sharp increase in depth per unit volume in the lake's deeper water suggests that very little of Cook Lake's volume is contained in the lake's deepest waters.

Table 11. Morphological characteristics of Cook Lake.

Cook Lake	
Surface Area	93 acres (37.6 ha)
Volume	1,647 acre-feet (2,031,114.6 m^3)
Maximum Depth	52 feet (15.8 m)
Mean Depth	17.7 feet (5.4 m)
Shoreline Length	11,341 feet (3,456.7 m)
Shoreline Development Ratio	1.6:1
Legal Lake Level	767.75 feet (234.0 m)

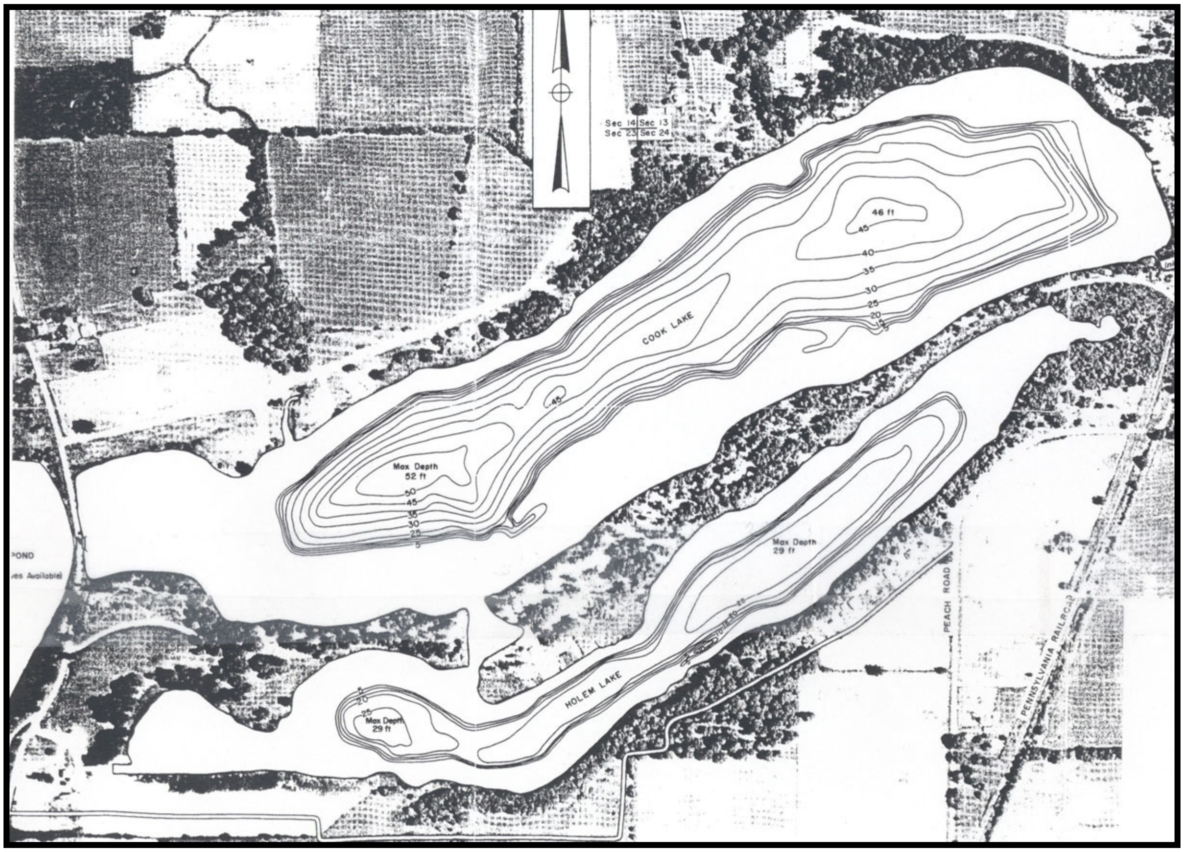

Figure 12. Bathymetric map for Cook and Holem Lakes.
Source: IDNR, 1964. Scale: 1”=800’.

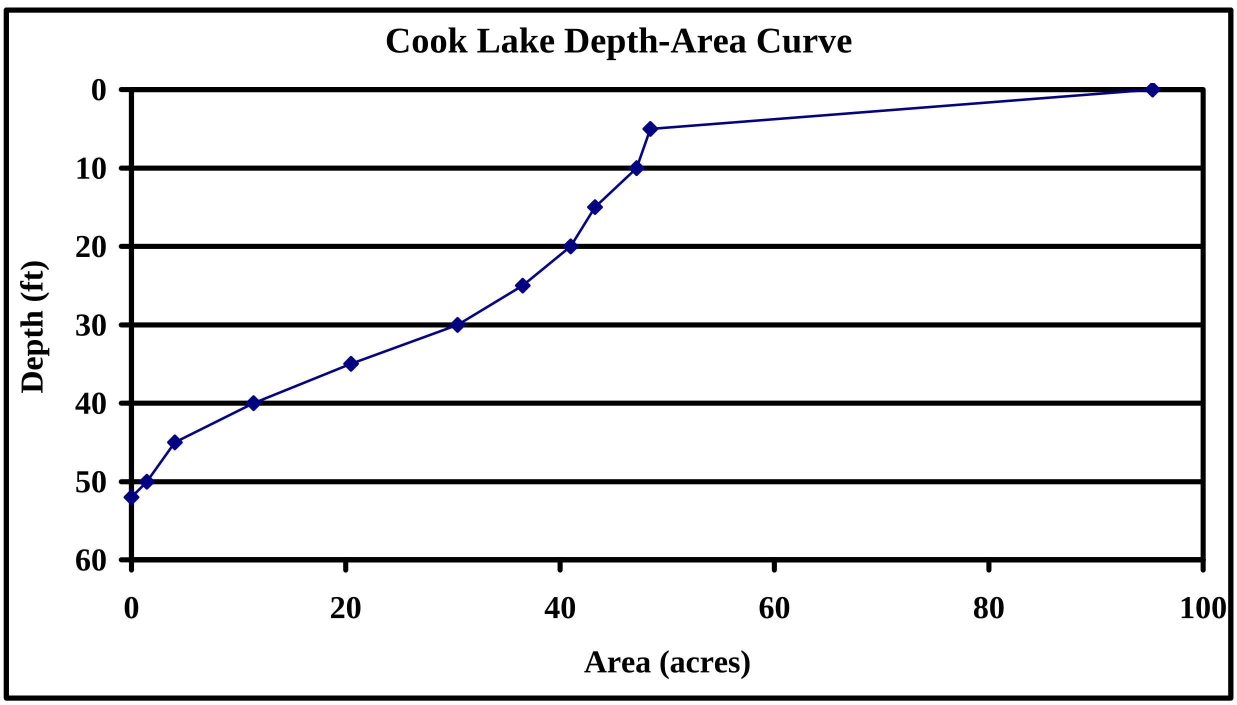

Figure 13. Depth-area curve for Cook Lake.

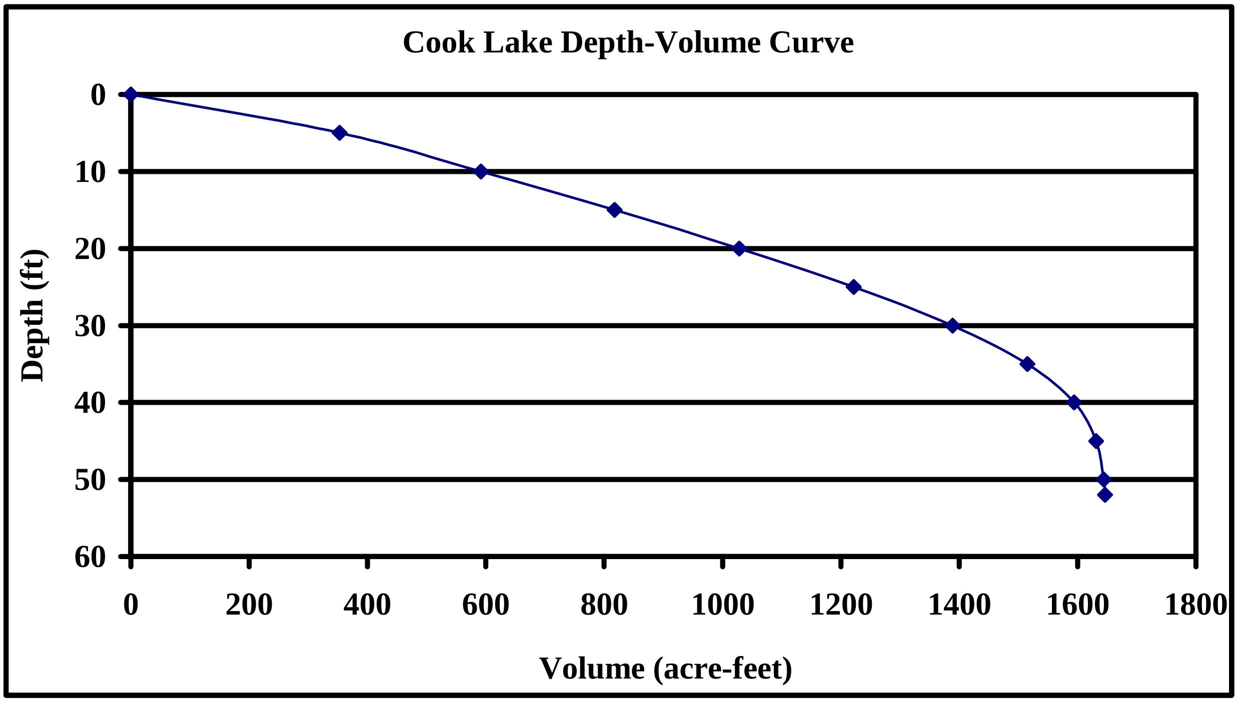

Figure 14. Depth-volume curve for Cook Lake.

Cook Lake's morphology influences both the biotic community within the lake and the human community located around the lake. For example, Cook Lake's extensive shallow area coupled with its relatively good clarity suggests that the lake is capable of supporting a large rooted plant community. Based on the lake's clarity, Cook Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 18.6 feet (5.7 m). Referring to Cook Lake's depth-area curve (Figure 13), this means that the lake's littoral zone is 50 acres (20.2 ha) in size and covers 54% of the lake. This large littoral zone can impact other biotic communities in the lake such as fish that use the plant community for forage, spawning, cover, and resting habitat.

The shoreline development ratio is a measure of the development potential of a lake. It is calculated by dividing a lake's shoreline length by the circumference of a circle that has the same area as the lake. A perfectly circular lake with the same area as Cook Lake (93 acres or 37.6 ha) would have a circumference of 7,135 feet (2,175 m). Dividing Cook Lake's shoreline length (11,341 feet or 3,456.7 m) by 7,135 feet yields a ratio of 1.6:1. This ratio is moderately low. The lack of extensive shoreline channeling typically observed at other popular Indiana lakes such as Lake Manitou results in Cook Lake's low shoreline development ratio. Given the immense popularity of lakes in northern Indiana, lakes with high shoreline development ratios are often highly developed. Increased development around lakes often leads to decreased water quality.

Cook Lake's size and shape or morphometry has been altered only slightly since the settlement of Marshall County. McDonald (1905) refers to Cook Lake as the largest of the Twin Lakes (which also include Holem and Myers Lakes) measuring three-quarters of a mile in length and one-half mile across. Mapping completed in 1876 by Baskin, Forster and Company refers to

Cook Lake as Northwest Twin Lake and indicates that Cook Lake covered roughly 90% of its current surface area. Although Cook Lake was mapped by Ogle and Company in 1922 as one of the Three Sisters Lakes, the shape and surface area of the lake changed little over the preceding 50 years. Morphometry variations observed between historic maps and the most current bathymetric maps could be due to advancement in measuring tools. The construction of Lake Latonka likely contributed to the difference in surface area historically mapped.

Residential development of the shoreline around Cook Lake likely began in the mid to late 1950s. The Marshall County Historical Society (1986) documents residential development around Lawrence Lake beginning in 1954 when Willard Lawrence sold 12 lots on the north side of the lake. Early aerial photography of the Cook Lake (1957) shows the presence of a limited number of houses and piers around Cook Lake, indicating that minimal development occurred at Cook Lake in a similar timeframe as that observed at Lawrence Lake. The houses and piers identified in the 1957 aerial are mostly located along the southern shoreline of the lake on the ridge separating Cook and Holem Lakes. Approximately ten additional houses are scattered along the northern shoreline of Cook Lake. The 1957 aerial photograph also documents the presence of a youth camp at the east end of the lake and a semi-permanent campground in what would become Camper's Roost along the northern shoreline. Forest, emergent wetland, and agricultural areas border the northeastern, southwestern, and northwestern shorelines.

By the 1970s, development covered much more of Cook Lake's shoreline than that observed in 1957. During the 1970 fisheries survey, Robertson (1971) estimated that approximately 40% of Cook and Holem Lake's shoreline was developed for residential use. (Fisheries surveys completed by the Indiana Department of Natural Resources consider Cook and Holem Lakes as one water body.) Robertson also noted the presence of the children's camp covering much of the eastern shoreline and identified four marinas and two resorts along the shores of Cook and Holem Lakes. Aerial photographs from 1973 confirm the presence of houses scattered along much of Cook Lake's northern shoreline with these houses more densely packed together than those present in 1957.

Development continued along Cook Lake's shoreline over the next 30 years. By 1999, Indiana Clean Lakes Program field biologists noted that nearly 75% of Cook Lake's shoreline was developed for residential land use. Aerial photographs from 1998 indicated that houses and mobile homes bordered nearly the entire northern shoreline of Cook Lake. Additional housing units added along the ridge separating Cook and Holem Lakes also increased the residential development of Cook Lake. In 2002, Price and Robertson (2003) estimated that residential development covered nearly 95% of Cook Lake's shoreline. As part of the current study, a count of the total number of homes indicated that 100 homes lie directly adjacent to Cook Lake's shoreline. Of these homes, an estimated 75% were utilized full time. Surveyors recorded the presence of an additional 49 homes located across the road from the shoreline. All of these homes were estimated to be full-time residences. In total, approximately 150 homes lie adjacent to Cook Lake.

Despite the ring of houses along Cook Lake's shoreline, nearly 66% of Cook Lake's shoreline is minimally or only moderately disturbed. (These areas are mapped as no seawall, minimally disturbed in Figure 15.) Trees and emergent vegetation have been thinned along approximately

36% of Cook Lake's shoreline. These areas possess at least a narrow band of emergent plants. Natural wetland buffers cover much of the western, southern, and northeastern shorelines of Cook Lake and, in some shallow locations like the eastern and western portions of the lake, are spreading into the lake. In total, approximately 30% of Cook Lake's shoreline remains in its natural state.

Approximately 34% of Cook Lake's shoreline has been completely altered from its natural state (Figure 15). Along approximately 12% of Cook Lake's shoreline emergent and floating rooted vegetation has been completely removed to expose sandy soils or mowed, residential lawns. Nearly 22% of Cook Lake's shoreline has been armored with protective material including wooden railroad timbers (13%), glacial stone or riprap (7%), or concrete seawalls (2%).

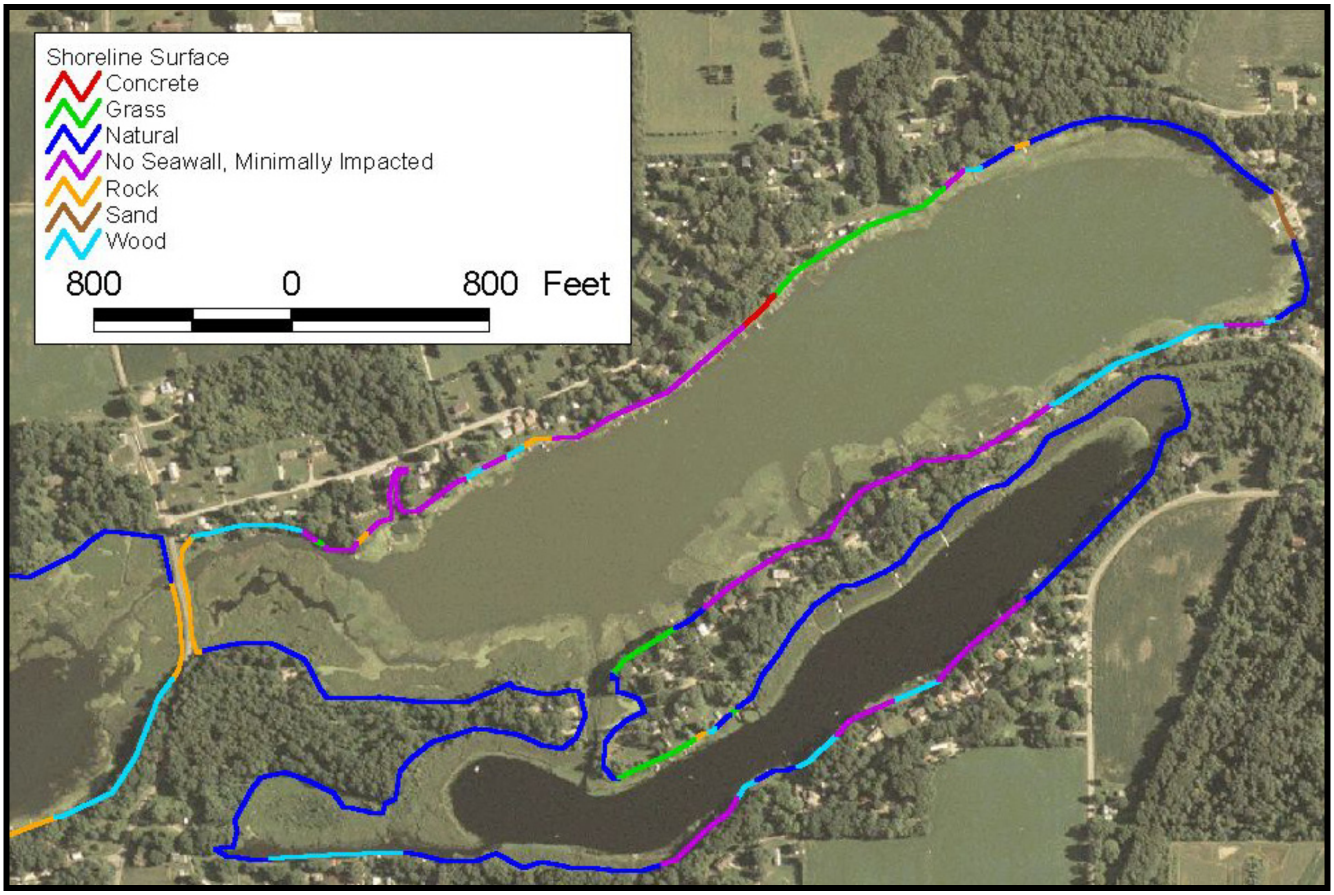

Figure 15. Shoreline surface type observed at Cook and Holem Lake, August 6, 2004.
Source: See Appendix A. Scale: 1"=800'.

The shoreline surface becomes especially important in and adjacent to shallow portions of Cook Lake. In areas where concrete seawalls are present, wave energy from wind and boats strike the flat surface and reflect back into the lake. This creates an almost continuous turbulence in the shallow areas of the lake. At points where the waves reflect back into the lake and meet incoming waves, the wave height increases resulting in further in-lake turbidity. This turbulence resuspends bottom sediments thereby increasing the transfer of nutrients from the sediment-water interface to the water column. Continuous disturbance in shallow areas can also encourage the growth of disturbance-oriented plants.

In contrast, shorelines vegetated with emergent or rooted floating vegetation or those areas covered by sand will absorb more of the wave energy created by wind or boats. In these locations, wave energy will dissipate along the shoreline each time a wave meets the shoreline surface. Similarly, glacial stone seawalls or those covered by wood can decrease shallow water turbulence and lakeward wave energy reflection while still providing shoreline stabilization.

3.1.2 Holem Lake

Figure 12 presents Holem Lake's morphology. Holem Lake is approximately 40 acres (16.2 ha) in size and has a volume of 387 acre-feet (477,356.7 m^3; Table 12). Holem Lake possesses a long narrow basin which lies parallel to Cook Lake and measures approximately 8,360 feet (2,548 m) in length and 960 feet (292 m) in width. The lake possesses two deep holes which are located near the eastern and western ends of the lake basin and extend to a depth of 29 feet (8.8 m). Water 20 to 25 feet (6.1 to 7.6 m) deep separates the two basins. Holem Lake possesses large expanses of shallow water. According to its depth-area curve (Figure 16), approximately 22.5 acres (9.1 ha or 57%) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 71.8% of the lake (28.75 acres or 11.6 ha) is less than 20 feet (6.1 m) deep. Figure 17 shows that the lake's volume gradually increases with depth to a depth of 25 feet (7.6 m) where the curve is much steeper over the final 5 foot (1.5 m) interval. The sharp increase in depth per unit volume in the lake's deeper water suggests that very little of Holem Lake's volume is contained in the lake's deepest waters.

Table 12. Morphological characteristics of Holem Lake.

Holem Lake	
Surface Area	40 acres (16.2 ha)
Volume	387 acre-feet (477,356.7 m^3)
Maximum Depth	29 feet (8.8 m)
Mean Depth	9.7 feet (2.9 m)
Shoreline Length	10,470 feet (3,191.3 m)
Shoreline Development Ratio	2.2:1
Legal Lake Level	767.75 feet (234.0 m)

Holem Lake's morphology influences both the biotic community within the lake and the human community located around the lake. For example, Holem Lake's extensive shallow area suggests the lake is capable of supporting a large rooted plant community. Based on the lake's clarity, Holem Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 8.4 feet (2.6 m). Referring to Holem Lake's depth-area curve (Figure 16), this means that the lake's littoral zone is 23.5 acres (9.5 ha) in size or 59 % of the lake. This means that nearly 60% of Holem Lake's surface area could support rooted plant growth. This large littoral zone can impact other biotic communities in the lake such as fish that use the plant community for forage, spawning, cover, and resting habitat. The similarity of Holem Lake's shape with that of Cook Lake's results in a shoreline development ratio exactly the same as Cook Lake's (1.6:1; Tables 11 and 12). This shoreline development ratio is moderately low and reflects the lack of channels on the lake.

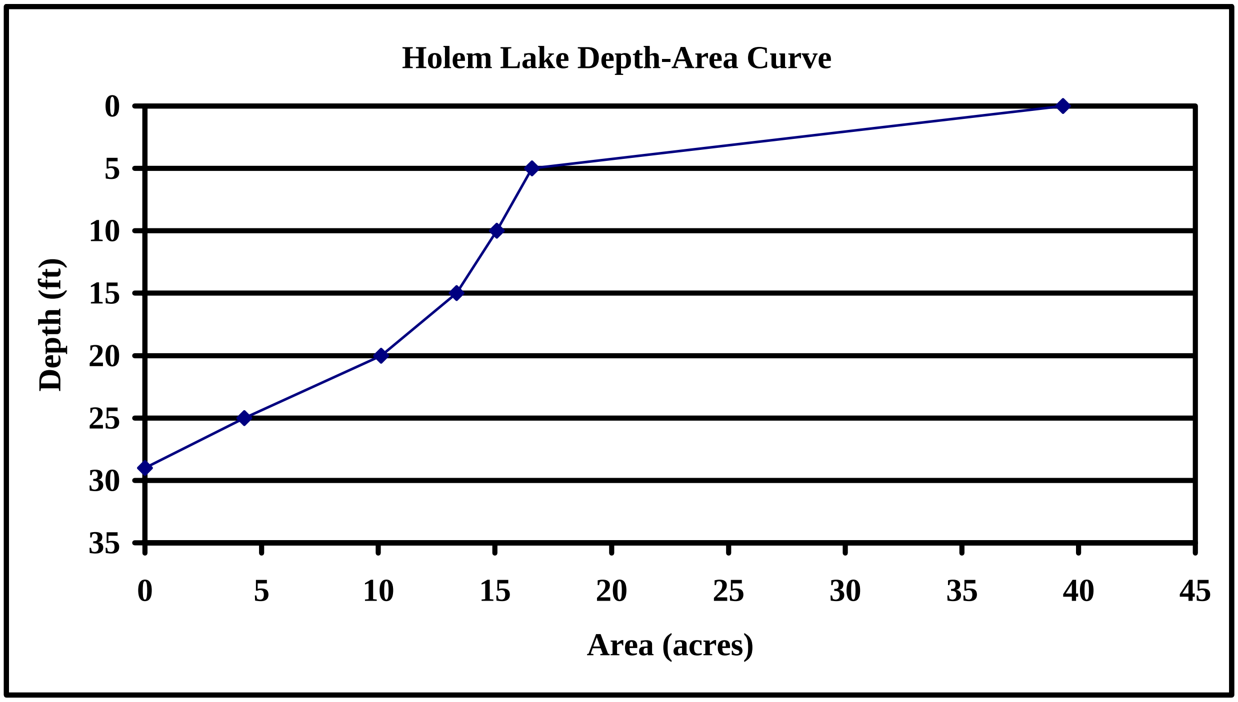

Figure 16. Depth-area curve for Holem Lake.

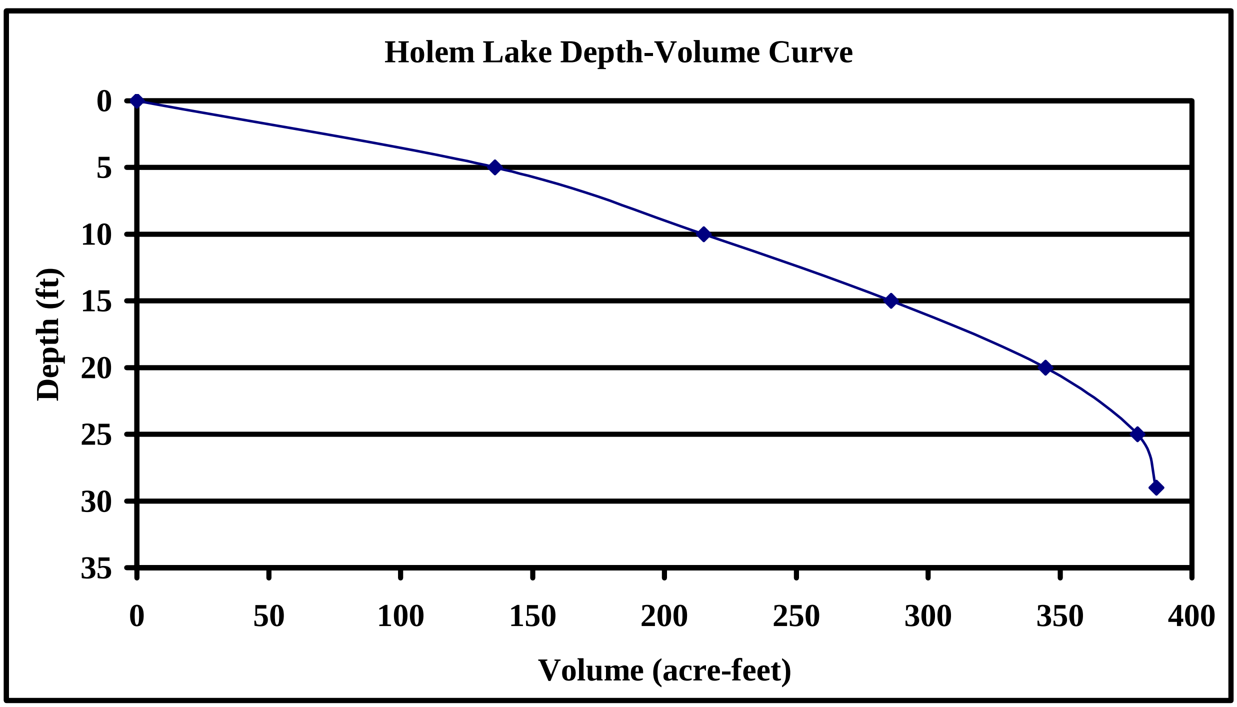

Figure 17 . Depth-volume curve for Holem Lake.

Like Cook Lake, Holem Lake's morphometry may have been altered only slightly since the settlement of Marshall County. McDonald (1905) refers to Holem Lake as the "smaller, marshy pond" of the Twin Lakes (which also include Cook and Myers Lakes). Mapping completed in 1876 by Baskin, Forster and Company and in 1899 by Blatchley refers to Holem Lake as

Southwest Twin Lake. Blatchley's survey documents the presence of steep banks with a narrow band of marshy ground between the lake's surface water and its shoreline. Additionally, Blatchley indicates that the lake measured three-quarters of a mile (3,960 feet or 1,207 m) long and roughly 500 feet (151 m) wide. In 1899, Holem Lake's basin was roughly one-half to two-thirds the size the lake is today. Variation in the portion of the adjacent emergent wetlands included as part of Holem Lake and advances in measurement instrumentation and precision likely account for some or all of the variation in lake size observed between historic and the most current mapping.

Residential development of the shoreline of Holem Lake is similar to that observed at Cook Lake. Early aerial photography of Holem Lake conducted in 1957 shows the presence of a few houses along the southeastern shoreline and along the ridge separating Cook and Holem Lakes. Forest, agricultural land, and emergent wetland covers the southern shoreline of Holem Lake. In 1970, Robertson estimated that approximately 40% of Cook and Holem Lake's shoreline was developed for residential use. Aerial photographs from 1973 confirm the presence of approximately 10 house near the southwestern end of Holem Lake and approximately 20 houses along the southeastern shoreline. The eastern and northwestern shorelines remained undeveloped in 1973. Over the next 25 years residential development continued. In 1999, Indiana Clean Lakes Program field biologists observed that 80% of the shoreline was developed for residential land use, while forest and wetland covered the remaining 20% of the lake's shoreline.

Currently, Holem Lake's shoreline appears much as it did in 1999. As part of the current study, a count of the total number of homes indicated that 61 homes lie directly adjacent to Holem Lake's shoreline. Of these homes, an estimated 80% were utilized full time. Surveyors recorded the presence of an additional 21 homes located across the road from the shoreline. All of these homes were estimated to be full-time residences. In total, approximately 82 homes lie adjacent to Holem Lake.

Despite the ring of houses along the shores of Holem Lake, much of Holem Lake's shoreline is vegetated by emergent or rooted floating plants (Figure 15). Nearly 75% of the shoreline remains in its naturally vegetated state. Typically, lake residents alter lake shorelines by filling wetland borders around lakes, removing emergent vegetation, and establishing manicured shorelines complete with seawalls. Holem Lake has been spared much of the destruction associated with residential development. Trees and emergent vegetation have been thinned along Holem Lake's southern shoreline; however, approximately 11% of the developed areas along the lake's shoreline possess at least a narrow band of emergent plants. Natural wetland buffers cover western, northern, and eastern shorelines of Holem Lake and, in some shallow locations like the eastern and western portions of the lake, are spreading into the lake. Given the small size, overall shallow nature, and the heavy plant growth present within Holem Lake, its primary use is likely aesthetic and low-impact recreation such as fishing, canoeing, and swimming. Shallow portions of the lake also serve as habitat for fish, amphibians, waterfowl, insects, and other water dependent species. These uses are compatible with and in some cases rely upon a well-vegetated shoreline like that present around much of Holem Lake. Additionally, emergent plant communities dampen wind-driven wave energy, thereby reducing the velocity at which waves impact the lake's shoreline.

Wooden railroad timbers, glacial rock, and mowed grass cover the remaining 14% of Holem Lake's shoreline. The narrow band of emergent wetland observed by Blatchley (1900) remains intact along much of the northern, western, southwestern, and eastern shorelines. Much of the southern shoreline has been altered and emergent vegetation removed as residential development increased in this area.

3.1.3 Kreighbaum Lake

Figure 18 presents Kreighbaum Lake's morphology. (For purposes of this discussion and throughout the report, the shoreline of Kreighbaum Lake is that demarcated by the boundary in Figure 18. All emergent wetland, shallow areas, and any other percentages discussed throughout this report are based on the acreage and volume calculated from this boundary.) Kreighbaum Lake is approximately 39 acres (15.8 ha) in size and possesses a volume of 425 acre-feet (524,228.9 m^3; Table 13). The lake consists of one deep basin 36 feet (11.0 m) deep surrounded by gradually shallower water. The deepest point of the lake occurs near the northeastern corner of the lake. Kreighbaum Lake possesses large expanses of shallow water. According to its depth-area curve (Figure 19), approximately 15 acres (38% or 6.1 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 81% (31.5 acres or 12.7 ha) of the lake is less than 20 feet (6.1 m) deep. The wetland connecting Kreighbaum and Millpond Lakes accounts for most of Kreighbaum Lake's surface area covering water less than 5 feet (1.5 m) deep. Figure 20 shows that the lake's volume gradually increased to a depth of 25 feet (7.6 m) where the curve gradually becomes steeper with each 5-foot (1.5-m) interval increase in depth. The sharp increase in depth per unit volume in the lake's deeper water suggests that very little of Kreighbaum Lake's volume is contained in the lake's deepest waters.

Table 13. Morphological characteristics of Kreighbaum Lake.

Kreighbaum Lake	
Surface Area	39 acres (15.8 ha)
Volume	425 acre-feet (524,228.9 m^3)
Maximum Depth	36 feet (11.0 m)
Mean Depth	10.9 ft (3.3 m)
Shoreline Length	4,532 feet (1,381.3 m)
Island Shoreline Length	1,490 feet (452.3 m)
Shoreline Development Ratio*	1.5:1
Legal Lake Level	767.75 feet (234.0 m)

*Including the shoreline of Kreighbaum Lake and the two islands.

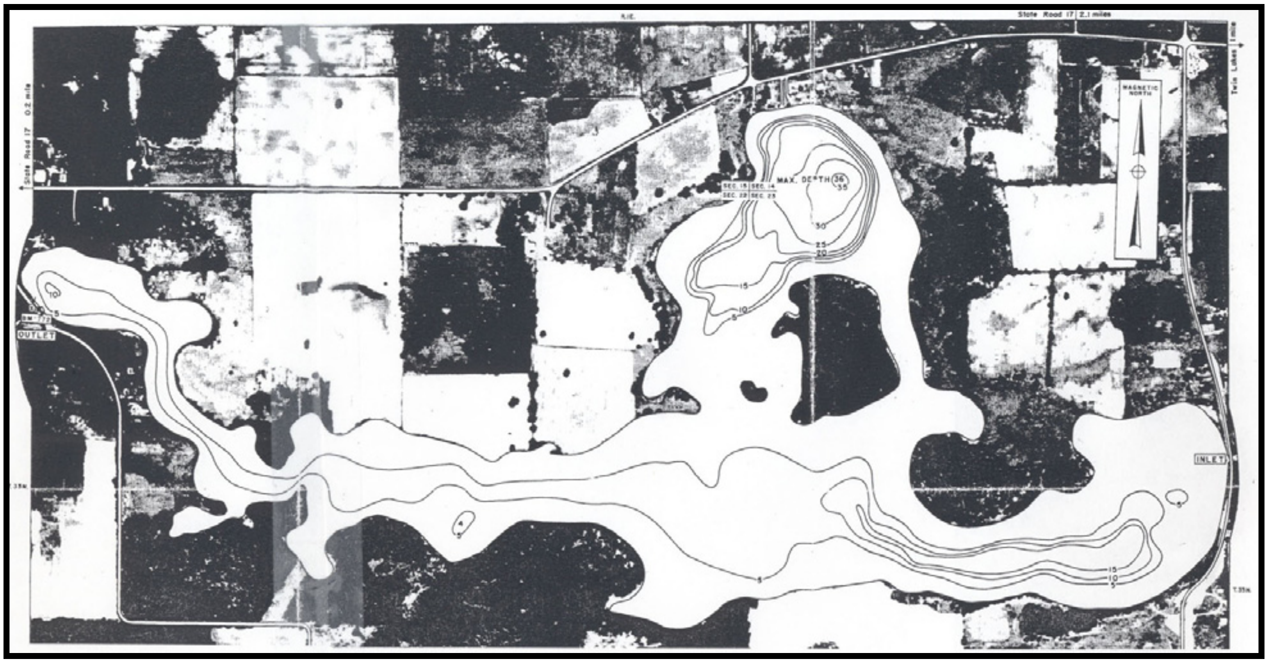

Figure 18. Bathymetric map for Kreighbaum and Millpond Lakes.
Source: IDNR, 1955. Scale: 1”=approximately 1,560’.

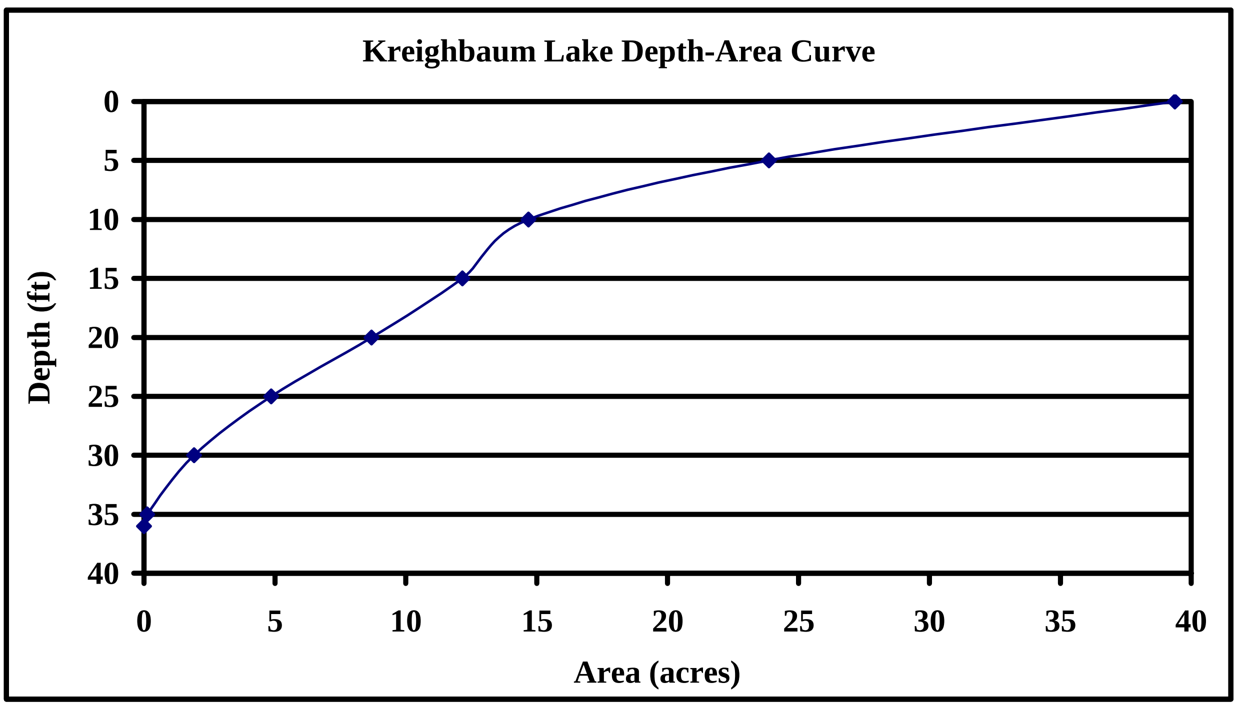

Figure 19. Depth-area curve for Kreighbaum Lake.

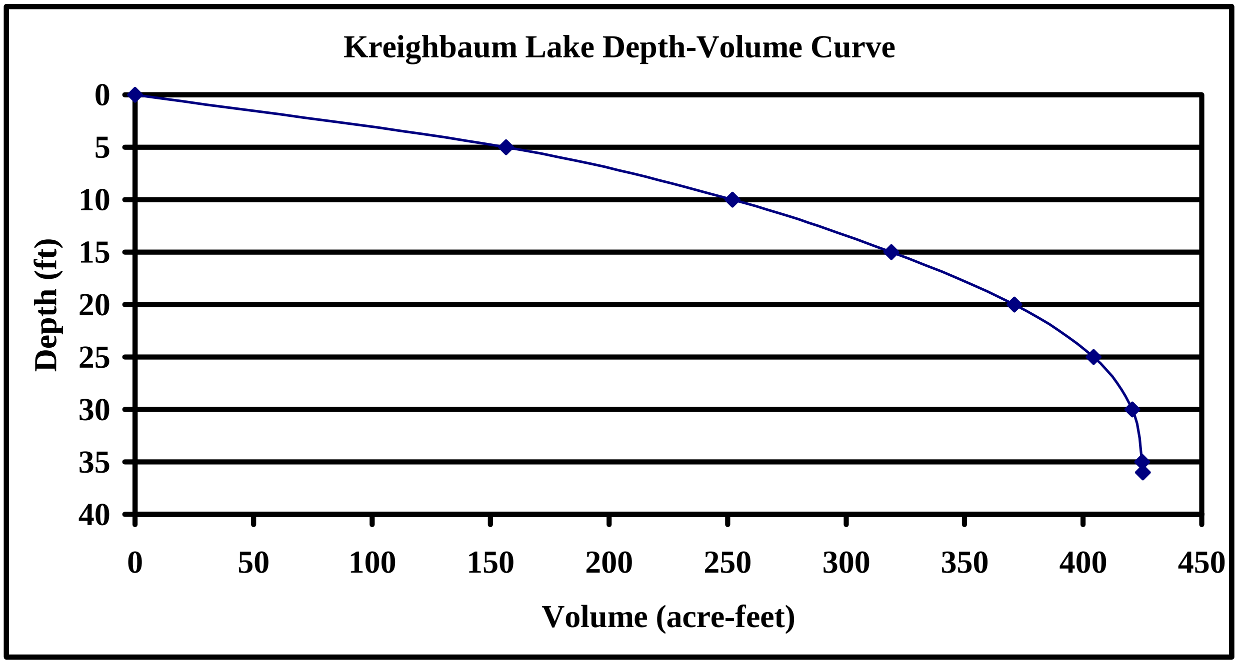

Figure 20. Depth-volume curve for Kreighbaum Lake.

Kreighbaum Lake's morphology influences both the biotic community within the lake and the human community located around the lake. For example, Kreighbaum Lake's extensive shallow area coupled with its excellent clarity suggests the lake is capable of supporting a large rooted plant community. Based on the lake's clarity, Kreighbaum Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 16.5 feet (5.0 m). Referring to Kreighbaum Lake's depth-area curve (Figure 18), this means that the lake's littoral zone is 27 acres (10.9 ha) in size or 69% of the lake. This means that nearly 70% of Kreighbaum Lake's surface area could potentially support rooted plant growth. This large littoral zone can impact other biotic communities in the lake such as fish that use the plant community for forage substrate, spawning, cover, and resting habitat. Kreighbaum Lake's shoreline development ratio is 1.5:1. The nearly circular shape of Kreighbaum Lake and the presence of the two islands that cover much of the southern portion of the lake results in the lowest shoreline development ratio of any of the Four Lakes. As with Cook and Holem Lakes, the lack of extensive shoreline channeling typically observed at other popular Indiana lakes such as Lake Manitou results in a low shoreline development ratio at Kreighbaum Lake.

Unlike Cook and Holem Lakes, Kreighbaum Lake's size and shape (morphometry) has been greatly altered since the settlement of Marshall County. Early maps of the area indicate that Kreighbaum Lake contained a smaller surface area than that which is present currently. The basin was nearly circular in shape and connected to Millpond Lake through a narrow stream channel (Baskin, Forster and Company, 1876; Ogle and Company, 1922). When Harry Cool Ditch was dammed to create Lake Latonka (Rowe, 1981) water flooded the shallow areas between Kreighbaum and Millpond Lakes changing the shape, surface area, and volume of Kreighbaum Lake.

Like Cook and Holem Lakes, residential development along the shoreline of Kreighbaum Lake began in the mid to late 1950s. Aerial photographs from 1951 show the presence of three houses along the northern shoreline of Kreighbaum Lake. Agricultural land, emergent wetland, and forest dominate the remainder of the lakeshore. By 1973, approximately ten houses border the northern and northeastern shoreline of Kreighbaum Lake. Estimates by Rowe (1981) indicate that roughly 10% of Kreighbaum and Millpond Lakes' shorelines were developed for residential uses. Within 25 years, the northeastern, northern, northwestern, and western shorelines of Kreighbaum Lake were developed. Indiana Clean Lakes Program field biologists estimated that residential development covered approximately 75% of Kreighbaum Lake's shoreline. Wetlands and forest bordered the remaining 25% of the lake's shoreline.

Development along the shores of Kreighbaum Lake has changed little over the past five years. Aerial photos from 2003 indicate that approximately 75% of Kreighbaum Lake's shoreline is covered by residential development. As part of the current study, a count of the total number of homes indicated that 42 homes lie directly adjacent to Kreighbaum Lake's shoreline. Of these homes, an estimated 75% are utilized full time. Surveyors recorded the presence of an additional 11 homes located across the road from the shoreline. All of these homes were estimated to be full-time residences. In total, approximately 53 homes lie adjacent to Kreighbaum Lake.

Despite the predominance of residential development, emergent and rooted floating plants vegetate much of Kreighbaum Lake's shoreline (Figure 21). Only two portions of the lake's shoreline have been completely cleared of emergent plants for the installation of an alternate shoreline cover. Residents removed emergent vegetation along the western shoreline replacing it with wooden railroad timbers which cover approximately 10% of the lakeshore. Additionally, vegetation was removed near the northwest corner of the lake exposing the natural sandy soils that are predominant within the area. The remaining 85% of the lake's shoreline contains at least a narrow band of emergent vegetation. In total, approximately 54% of Kreighbaum Lake's shoreline, most notably the eastern and southwestern portions of the shoreline, remain in its naturally vegetated state.

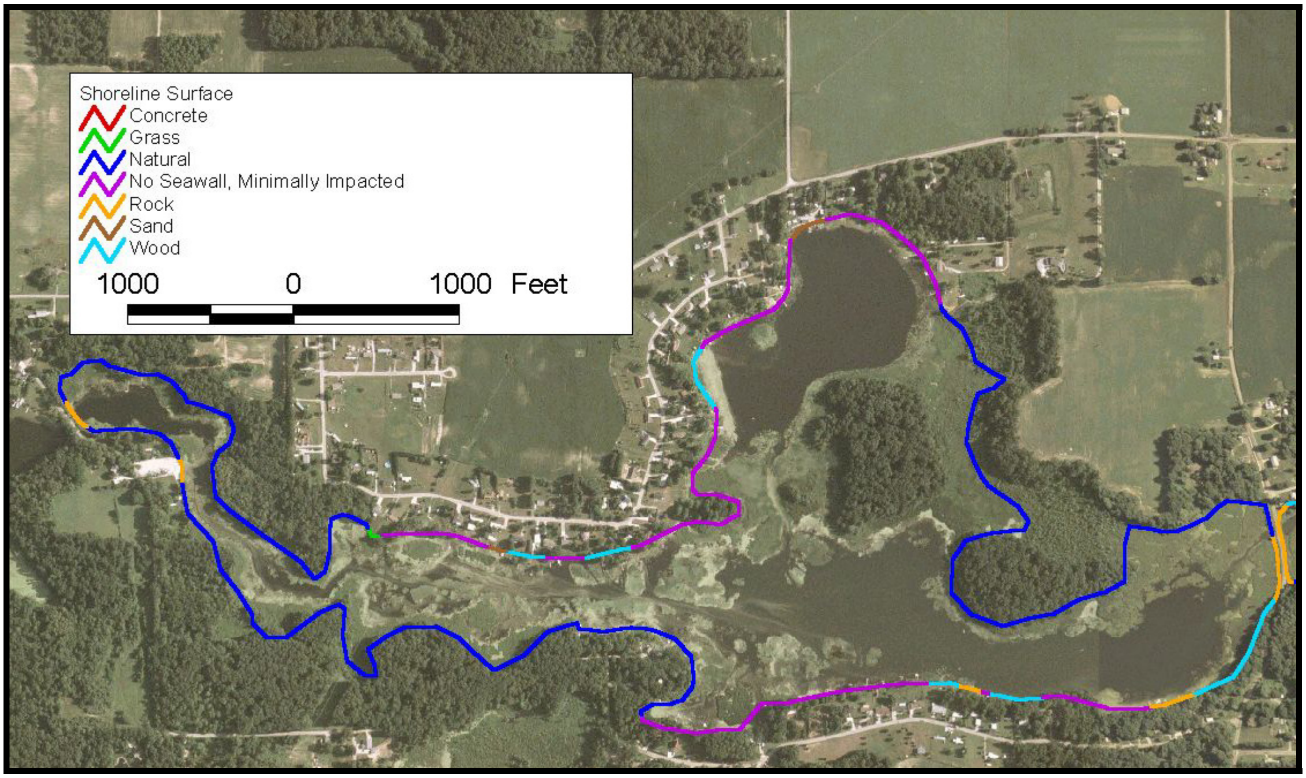

Figure 21. Shoreline surface type observed at Kreighbaum and Millpond Lakes, August 6, 2004.
Source: See Appendix A. Scale: 1"=1,200'.

3.1.4 Millpond Lake

Figure 18 presents Millpond Lake's morphology. Millpond Lake is approximately 129 acres (52.2 ha) in size and contains a volume of 578 acre-feet (712,951; Table 14). Millpond Lake possesses a long narrow basin, which extends approximately 8,000 feet (2,438 m) in length from east to west and varies from 200 feet to 1160 feet (60.9 to 353.6 m) in width from north to south. Two deep holes measuring 10 feet (3.1 m) and 15 feet (4.6 m) are located at the west and east ends of the lake, respectively. Water 5 feet (1.5 m) deep or shallower separates the two holes. Millpond Lake possesses large expanses of shallow water. According to its depth-area curve (Figure 22), approximately 85 acres (34.4 ha or 66%) of the lake is covered by water less than 5 feet (1.5 m) deep, while nearly 98% of the lake (127 acres or 51.4 ha) is less than 15 feet (4.6 m) deep. Figure 23 shows that the lake's volume gradually increased to a depth of 10 feet (3.1 m) where the curve gradually becomes steeper with each 5-foot (1.5-m) interval increase in depth. The sharp increase in depth per unit volume in the lake's deeper water suggests that very little of Millpond Lake's volume is contained in the lake's deepest waters.

Table 14. Morphological characteristics of Millpond Lake.

Millpond Lake	
Surface Area	129 acres (52.2 ha)
Volume	578 acres-feet (712,951.4 m^3)
Maximum Depth	15 feet (4.6 m)
Mean Depth	4.5 feet (1.4 m)
Shoreline Length	22,373 feet (6,819.3 m)
Shoreline Development Ratio*	2.8:1
Legal Lake Level	767.75 feet (234.0 m)

* Including the shoreline of Millpond Lake and the two islands.

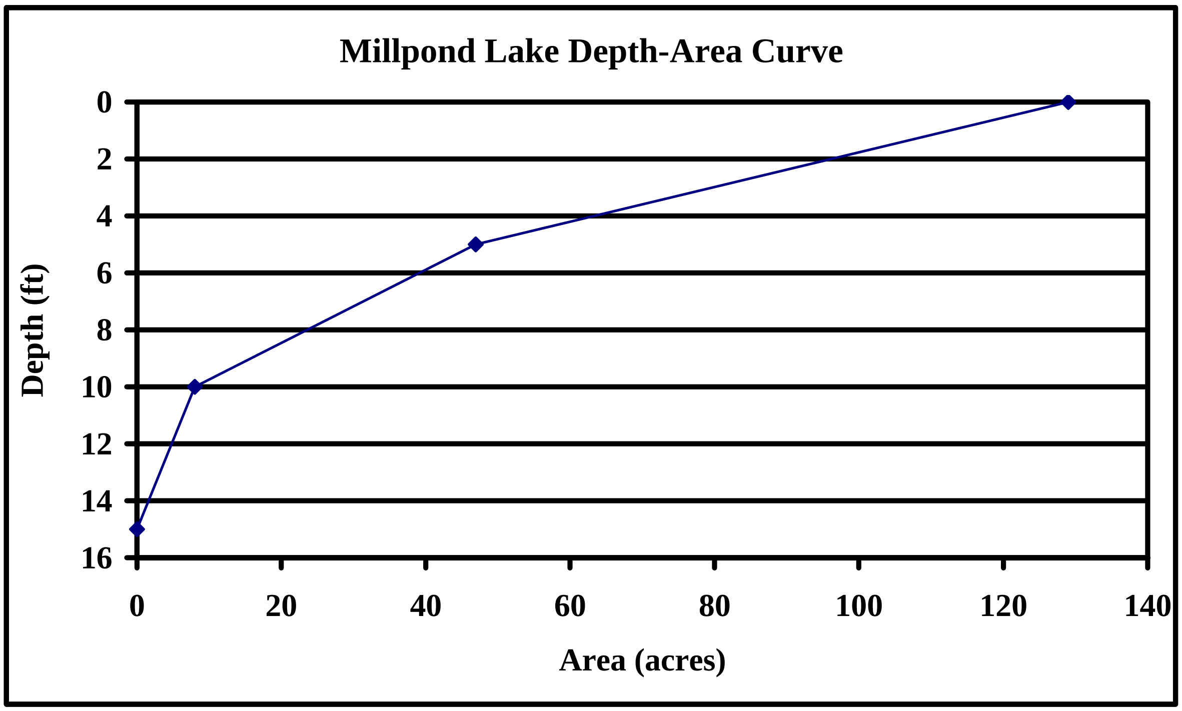

Figure 22. Depth-area curve for Millpond Lake.

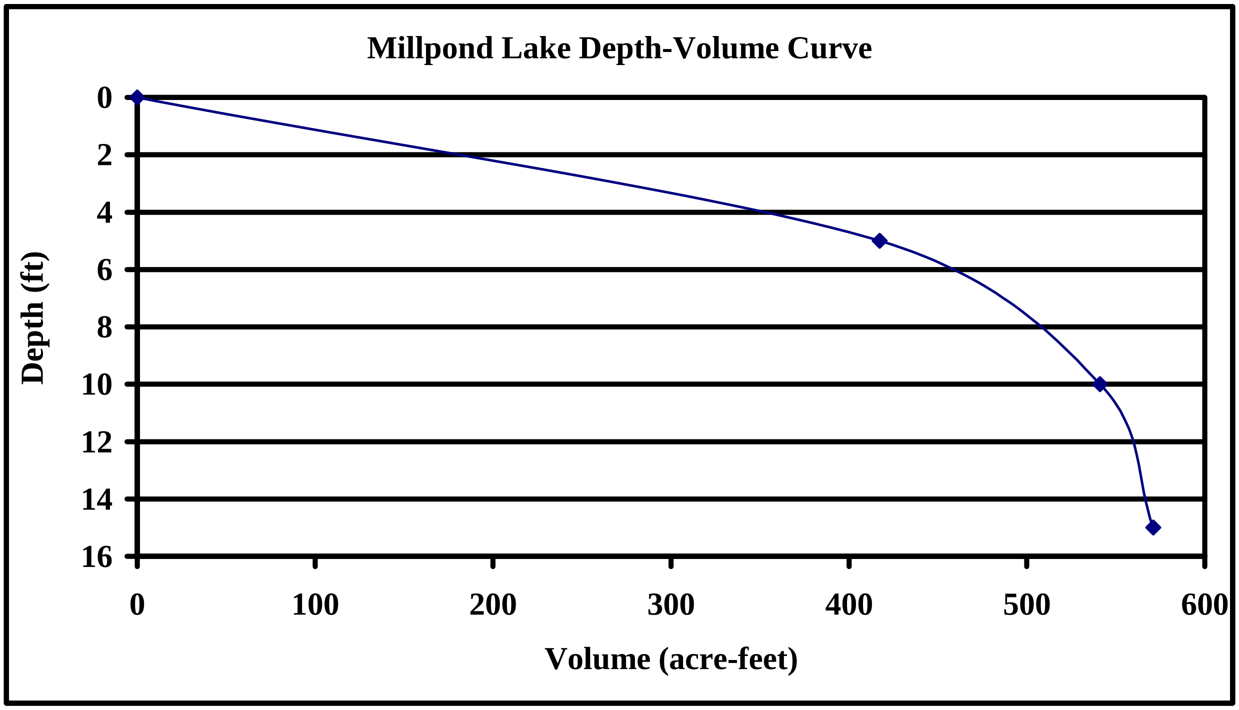

Figure 23. Depth-volume curve for Millpond Lake.

Millpond Lake's morphology influences both the biotic community within the lake and the human community located around the lake. For example, Millpond Lake's extensive shallow area suggests the lake is capable of supporting a large rooted plant community. Based on the lake's clarity, Millpond Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to 15 feet (4.6 m), the maximum depth of the lake. This means that the lake's littoral zone covers the entire lake. The shallow nature of the lake coupled with the good transparency can impact other biotic communities in the lake such as fish that use the plant community for forage, spawning, cover, and resting habitat. Millpond Lake's shoreline development ratio is the highest of any of the Four Lakes (2.8:1). The number of embayments and the long, narrow shape of the lake create a long interface between the terrestrial and aquatic habitat. However, when comparing this ratio with other popular recreational lakes, this ratio is relatively low.

Millpond Lake, originally named Zehner Millpond, was created in 1832 (Faulkner, 1961). The Millpond created power for the first grist mill in Marshall County. Individuals selected this location based on three reasons: the gradient of Forge Creek as it exited the Twin Lakes, the continuous supply of flowing water created by the lakes located upstream, and the fact that the area was not subject to flooding (Anderson, 1987). The shallow nature of Millpond Lake is detailed in maps completed by Baskin, Forster and Company (1876). Maps indicate that wetlands extend north to 12th Road and south to 14th Road. Much of the remaining shoreline was covered by forest or utilized for agricultural production. Over the next 90 years, mining of ore from the surrounding areas continued. However, the area was gradually abandoned. The grist mill stood on its original location until 1922 when individuals cleared the surrounding woods and removed the building in order to create additional farm land (Swindell, 1923).

The morphometry of and development along Millpond Lake's basin has changed little since 1923. Aerial photographs from the early 1950s indicate that few houses were located along Millpond Lake's shoreline. Agricultural land covered much of the northern shoreline of Millpond Lake. The 1957 aerial indicates that one house was located along the southeastern shoreline and two houses were located along the northwestern embayment. By 1973, approximately fifteen houses bordered Millpond Lake. The houses and piers identified in the 1973 aerial photographs are mostly located around the northwestern bay and along the southern shoreline. Agricultural fields bordered the northern shoreline with emergent wetland and forested land along much of the southern shoreline of Millpond Lake. Development continued through the 1980s, when approximately 10% of Kreighbaum and Millpond Lakes' shorelines were developed (Robertson, 1980), through the late 1990s. Aerial photographs from 1998 indicate that much of the northern, northwestern, and southern shorelines were developed. In 1999, Indiana Clean Lakes Program field biologists estimated that 60% of Millpond Lake's shoreline was developed for residential use.

Shoreline development has changed little over the past five years. As part of the current study, a count of the total number of homes indicated that approximately 70 homes lie directly adjacent to Millpond Lake. Of these homes, an estimated 90% are utilized full time. Surveyors recorded the presence of an additional 38 homes located across the road from Millpond Lake's shoreline. All of these homes were estimated to be full-time residences. In total, approximately 110 homes lie adjacent to Millpond Lake. Like Kreighbaum Lake, much of Millpond Lake's shoreline is vegetated by emergent or rooted floating plants. Shorelines in their naturally vegetated form cover approximately 63% of Millpond Lake's shoreline, while approximately 22% of the shoreline contains at least a minimal fringe of emergent vegetation. Glacial rock, wooden railroad timbers, sand, and grass cover approximately 15% of the shoreline. Figure 21 displays areas where emergent vegetation has been replaced with alternate shoreline cover.

3.2 Historical Water Quality Data

3.2.1 Cook Lake

The Indiana Department of Natural Resources, Division of Fish and Wildlife, the Indiana State Pollution Control Board, volunteer monitors, and the Indiana Clean Lakes Program have conducted various water quality tests on Cook Lake. Table 15 presents a summary of some selected water quality parameters from these assessments of Cook Lake.

Secchi disk transparency depths gradually declined from the 1970s to the 1990s before rebounding in the last few years (Table 15). The IDNR Division of Fish and Wildlife recorded a Secchi disk transparency depth of 10.5 feet (2.3 m) in 1970, the highest summertime Secchi disk transparency recorded for Cook Lake. Water clarity declined in the years following 1970, reaching a low of 2.3 feet (0.7 m) in 1989. Secchi disk transparency increased slightly during the 1990s ranging from 2.3 to 3.0 feet (0.7 to 0.9 m). Measurements recorded in 2004 indicate that transparency is improving within Cook Lake. (Both IU-SPEA and JFNew measured Secchi disk transparency depths of 6.2 feet (1.9 m) at different times in 2004 at Cook Lake.) However, Cook Lake's transparency remains below the median transparency recorded in Indiana lakes. Despite seasonal variation, Secchi disk transparencies observed by the Indiana Clean Lakes Program, IDNR Division of Fish and Wildlife, and volunteer monitors over the past 15 years show a slight trend of decreasing transparency over time (Figure 24). The best transparency measurement recorded by volunteers (13.75 feet or 4.1 m) was recorded in May 1991. The worst transparency reading (2.25 feet or 0.7 m) occurred in both July and September of 1990). These readings follow typical patterns observed in lakes throughout Indiana. Transparency is at its best near the start and end of the growing season (typically April to June and late September to October). Poor Secchi disk transparencies, such as those observed in Cook Lake in 1990, typically occur in Indiana lakes during July and August when algal and non-algal turbidities are at their highest.

Table 15. Summary of historic data for Cook Lake.

Date	Secchi (ft)	Percent Oxic (%)	Mean TP (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Data Source
7/7/1970	10.5	63%	--	--	--	Robertson, 1971
1970s	9.0	--	0.18*	--	40[§]	IDEM, 1986
6/6/1976	7.0	63%	--	--	--	Robertson, 1977
6/11/1989	2.3	20%	0.267	5,804	43	CLP, 1989
1990	2.8[cs]	--	--	--	--	Volunteer Monitor, 1990
1992	3.3[cs]	--	--	--	--	Volunteer Monitor, 1992
7/19/1995	2.3	13%	0.295	543,219	64	CLP, 1995
7/31/1999	3.0	20%	0.055	3,018	29	CLP, 1999
6/10/2002	3.6	--	--	--	--	Robertson and Price, 2003
2002	4.8[cs]	--	--	--	--	Volunteer Monitor, 2002
2003	3.9[cs]	--	--	--	--	Volunteer Monitor, 2003
2004	4.4[cs]	--	--	--	--	Volunteer Monitor, 2004
8/1/2004	6.2	27%	0.223	5,803	32	Present Study

* Water column average; all other values are mean of epilimnion and hypolimnion values.
[§] Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.
[cs]Volunteer monitoring data collected through the Indiana Clean Lakes Volunteer Monitoring Program. Data displayed in the table represent median values for data collected annually during July and August.

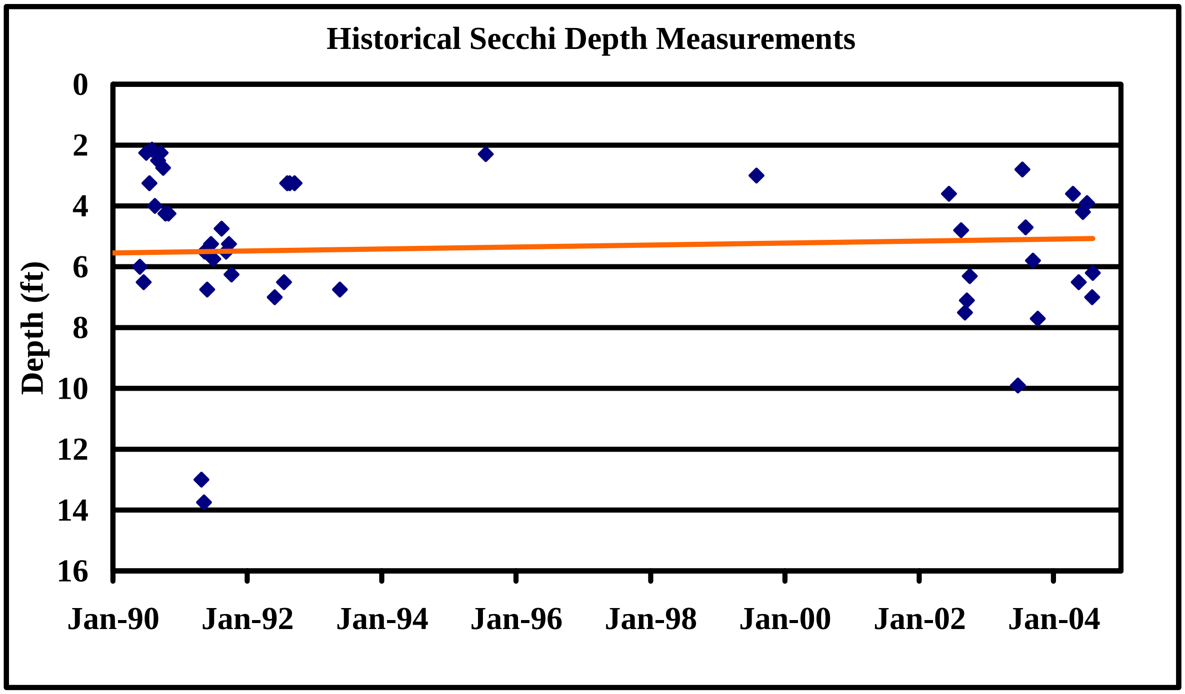

Figure 24. Historical Secchi disk transparency data for Cook Lake sampled by the Indiana Clean Lakes Program, IDNR Division of Fish and Wildlife, and the Indiana Clean Lakes Volunteer Monitoring Program.

Most of the data in Table 15 suggest that water quality within Cook Lake is slightly poorer than most Indiana lakes. Measurements recorded in the 1970s indicate that nearly 63% of the water column contained sufficient oxygen to support healthy biotic communities. However, data recorded over the past 15 years indicate that only 20% to 27% of the water column was adequately oxygenated. Total phosphorus and concentrations have been variable over the past 35 years (Table 15). The lowest total phosphorus concentration (0.055 mg/L) occurred in 1999, which corresponds with the least dense plankton community. Likewise, the highest total phosphorus concentration was observed in 1995 and corresponds with the densest plankton community. In every year except 1999, hypolimnetic total phosphorus concentrations exceeded epilimnetic phosphorus concentrations. Much of this total phosphorus was comprised of soluble reactive phosphorus (SRP), suggesting that the lake was releasing the phosphorus from its bottom sediments.

The Indiana TSI scores indicate that overall productivity increased from the 1970s to 1995 before decreasing to levels currently observed in Cook Lake. In the 1970s, the TSI score of 40 indicated that the lake was eutrophic. The increase in TSI score to 64 in 1995 suggests that the lake's productivity increased. The 1995 TSI score places the lake in the hypereutrophic category. Results from the 1999 and 2004 (current) surveys place the lake at the upper end of the mesotrophic category to the lower end of the eutrophic category.

Figures 25 and 26 display dissolved oxygen and temperature profiles recorded during IDNR fisheries surveys and Indiana Clean Lakes Program (CLP) assessments. All of the temperature profiles show the Cook Lake was stratified. The temperature profiles observed by the IDNR

Division of Fish and Wildlife during the 1970s and 2003 fisheries surveys were recorded early in the growing season resulting in weaker stratification than is present during survey conducted during the 1990s. The strongly developed hypolimnion present during the 1995 and 1999 surveys is typical of Indiana lakes. In 1995, the lake was anoxic below 10 feet (3.0 m). The 1989 and 1999 profiles exhibit slightly better oxygen conditions with anoxia occurring below 13 feet (3.9 m). The 1970 and 1976 sampling profiles illustrate different conditions than those observed from 1989 to 1999. In the 1976 dissolved oxygen profile there is a sharp increase in dissolved oxygen in the lake's metalimnion. This results in a positive-heterograde profile. Positive-heterograde profiles are characterized by a peak in oxygen concentration at a depth below the water surface, such as the peak in the 1976 profile beginning around 15 feet (4.6 m) below the water surface. The peak is likely associated with a higher concentration in phytoplankton at that particular depth layer. Called a ***metalimnetic oxygen maximum***, the peak results when the rate of settling plankton slows in the denser waters of the metalimnion. At this depth, the plankton can take advantage of nutrients diffusing from the nutrient-enriched hypolimnion. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating the peak in oxygen at that level.

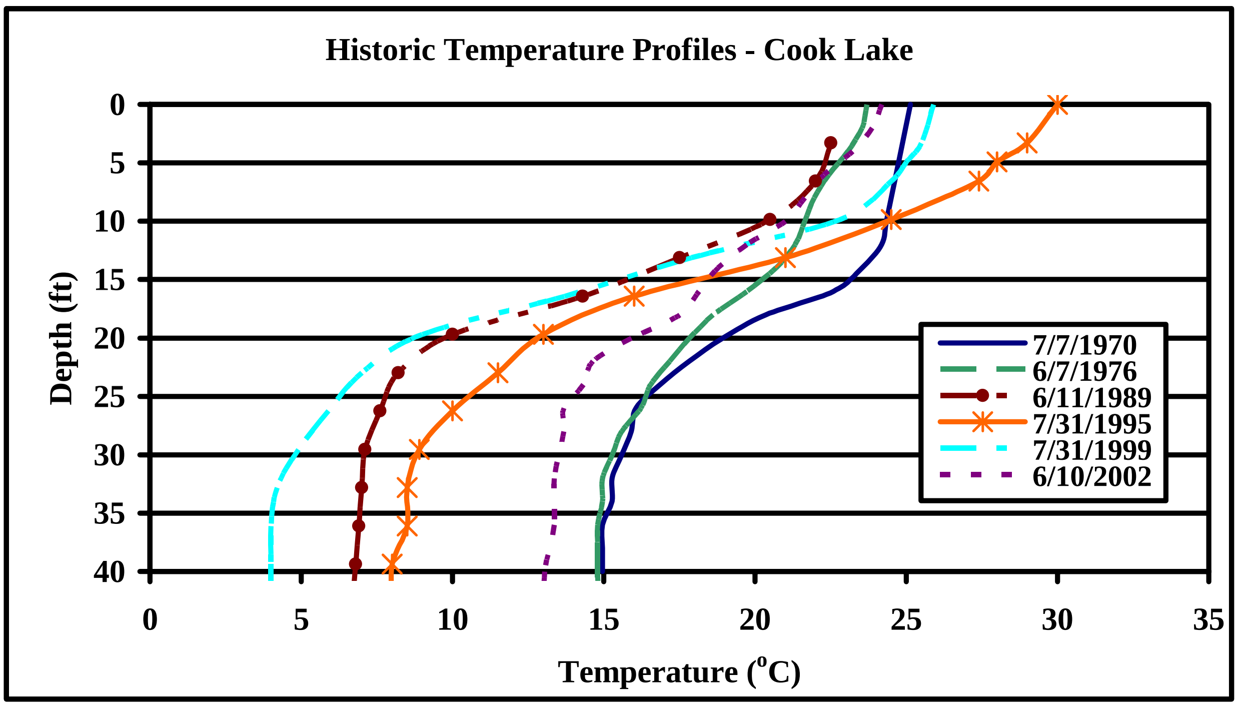

Figure 25. Historical temperature profiles for Cook Lake.
Source: Robertson, 1971; Robertson, 1977; CLP, 1989, 1995, and 1999; Robertson and Price, 2003.

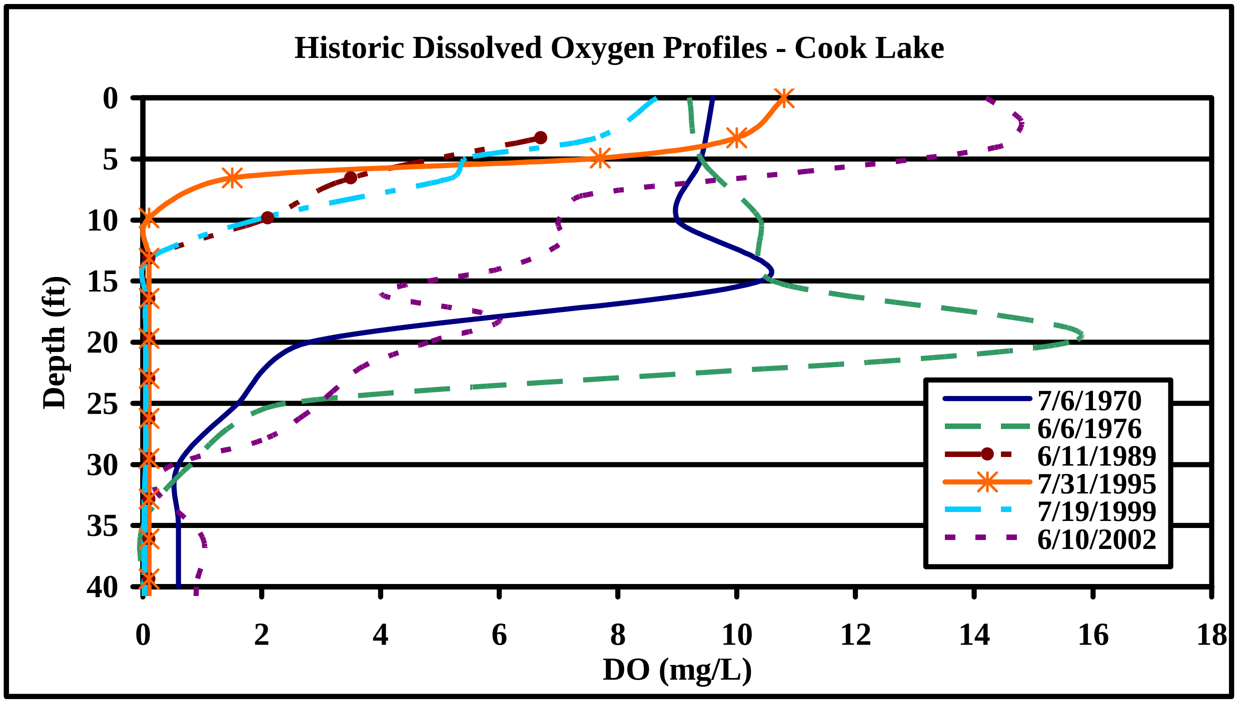

Figure 26. Historical dissolved oxygen profiles for Cook Lake.
Source: Robertson, 1971; Robertson, 1977; CLP, 1989, 1995, and 1999; Robertson and Price, 2003.

The data displayed in Tables 16 through 18 contain summary data from the Indiana Clean Lakes Program comprehensive assessments. The data indicate that, in general, water quality conditions have declined and Cook Lake is best described as a eutrophic to hypereutrophic lake. Water clarity in the 1990s was poor. Secchi disk transparency depth measured a maximum of 3 feet (0.9 m). During the same time period, a maximum of 16% of the incident light reached a water depth of 3 feet. (In clearer lakes, light transmission at 3 feet can be expected to exceed 50%.) By a depth of approximately 8 feet (2.4 m), light had been extinguished to the point where photosynthesis could not be supported. This limits the habitat availability for rooted plants. Historic data also shows that Cook Lake supported a healthy algal population. The concentration of chlorophyll *a* was very high, measuring 45 μg/L in 1995 and 28 μg/L in 1999. Chlorophyll *a* concentrations of this magnitude are usually characteristic of hypereutrophic lakes. Plankton populations measured in 1995 (Table 17) were greater than ten times the median concentration observed in Indiana lakes. In 1989 and 1995, blue-green algae, a nuisance algae associated with productive lakes, represented greater than 90% of the Cook Lake algal community. The low density plankton population and lack of blue-green algal dominance during the 1999 survey resulted in a lower Indiana TSI score than those observed during 1995 and 1999. (The Indiana TSI relies strongly on the algal population for score computation. Other comparison methods may provide a more comparable measurement of Cook Lake's productivity than the ITSI.) Elevated nutrient concentrations and poor Secchi disk transparency indicate that something other than light was limiting the algal population during the 1999 assessment. Combined, this data suggest Cook Lake was best described as a eutrophic to hypereutrophic lake at the time of the 1989, 1995, and 1999 CLP sampling.

Table 16. Historical water quality characteristics of Cook Lake, June 11, 1989.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
Secchi Depth Transparency	0.7 m	-	6
Light Transmission @ 3 ft.	10%	-	4
Total Phosphorous	0.063 mg/L	0.471 mg/L	4
Soluble Reactive Phosphorous	0.003 mg/L	0.442 mg/L	4
Nitrate-Nitrogen	0.943 mg/L	1.916 mg/L	3
Ammonia-Nitrogen	0.031 mg/L	3.270 mg/L	4
Organic Nitrogen	1.631 mg/L	0.927 mg/L	3
Oxygen Saturation @ 5ft.	58%	-	0
% Water Column Oxic	20%	-	4
Plankton Density	3,100/L	-	1
Blue-Green Dominance	96.7%	-	10
		TSI Score	**43**

Table 17. Historical water quality characteristics of Cook Lake, July 31, 1995.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.7	6.6	-
Alkalinity	145 mg/L	212 mg/L	-
Conductivity	370 μmhos	315 μmhos	-
Secchi Depth Transparency	0.7 m	-	6
Light Transmission @ 3 ft.	10%	-	4
1% Light Level	5.8 ft	-	-
Total Phosphorous	0.057 mg/L	0.533 mg/L	4
Soluble Reactive Phosphorous	0.005 mg/L	0.535 mg/L	4
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.039 mg/L	2.837 mg/L	4
Organic Nitrogen	1.594 mg/L	1.071 mg/L	3
Oxygen Saturation @ 5ft.	98.3%	-	0
% Water Column Oxic	13.2%	-	4
Plankton Density	543,219/L	-	25
Blue-Green Dominance	93.2%	-	10
Chlorophyll-a	45.82 μg/L	-	-
		TSI Score	**64**

Table 18. Historical water quality characteristics of Cook Lake, July 19, 1999.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.7	5.7	-
Alkalinity	135 mg/L	200.5 mg/L	-
Conductivity	371 μmhos	295 μmhos	-
Secchi Depth Transparency	0.9 m	-	6
Light Transmission @ 3 ft.	16%	-	4
1% Light Level	8.4 ft	-	-
Total Phosphorous	0.046 mg/L	0.063 mg/L	3
Soluble Reactive Phosphorous	0.010 mg/L	0.410 mg/L	4
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	2.082 mg/L	4
Organic Nitrogen	1.432 mg/L	0.702 mg/L	3
Oxygen Saturation @ 5ft.	66%	-	0
% Water Column Oxic	20%	-	4
Plankton Density	3,017/L	-	1
Blue-Green Dominance	29.7%	-	0
Chlorophyll-a	28.17 μg/L	-	-
		TSI Score	**29**

3.2.2 Holem Lake

The Indiana Department of Natural Resources, Division of Fish and Wildlife, the Indiana State Pollution Control Board, volunteer monitors, and the Indiana Clean Lakes Program have conducted various water quality tests on Holem Lake. Table 19 presents some selected water quality parameters for these assessments of Holem Lake.

The data in Table 19 suggest that the water quality in Holem Lake is typical or slightly better than most Indiana lakes. Secchi disk transparency depths fluctuated from year to year, but in all years except 1989 and 2004, Secchi disk transparency depths were greater than the median Secchi disk transparency depth for Indiana lakes. Transparency generally increased from the 1970s to 1999, when a record transparency of 11.5 feet (3.5 m) was observed. Secchi disk transparency declined from 1999 to 2004 reaching a low of less than 3.0 feet (0.9 m), which was recorded by both IU-SPEA and JFNew during the current assessment. Although the Secchi disk transparency was seasonally variable, it shows neither an increasing nor a decreasing trend in transparency over time (Figure 27). Total phosphorus concentrations were elevated in 1989 but declined to moderate levels for Indiana lakes in 1995. Concentrations increased over the past 10 years but remained below the median concentration observed in Indiana lakes. Historic total phosphorus concentrations indicate that Holem Lake likely supported algal blooms in the summer. In 1989, measurements indicate that nearly 75% of the water column contained sufficient oxygen to support healthy biotic communities. However, only 38% of the water column contained sufficient oxygen during the current assessment. This decrease in oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments.

Table 19. Summary of historic data for Holem Lake.

Date	Secchi (ft)	Percent Oxic (%)	Mean TP (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Data Source
1970s	8.5		0.03*	--	23§	IDEM, 1986
6/11/1989	6.2	75%	0.254	94,487	41	CLP, 1989
1990	8.4☙	--	--	--	--	Volunteer Monitor, 1990
1991	9.1☙	--	--	--	--	Volunteer Monitor, 1991
1992	11.3☙	--	--	--	--	Volunteer Monitor, 1992
7/19/1995	10.5	50%	0.089	24,705	30	CLP, 1995
7/31/1999	11.5	50%	0.118	2,017	23	CLP, 1999
2002	8.2☙	--	--	--	--	Volunteer Monitor, 2002
2003	9.5☙	--	--	--	--	Volunteer Monitor, 2003
6/10/2003	7.0	63.6%	--	--	--	Robertson and Price, 2003
2004	5.1☙	--	--	--	--	Volunteer Monitor, 2004
8/11/2004	3.0	38%	0.123	21,883	39	Present Study

* Water column average; all other values are mean of epilimnion and hypolimnion values.
§ Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.
☙Volunteer monitoring data collected through the Indiana Clean Lakes Volunteer Monitoring Program. Data displayed in the table represent median values for data collected annually during July and August.

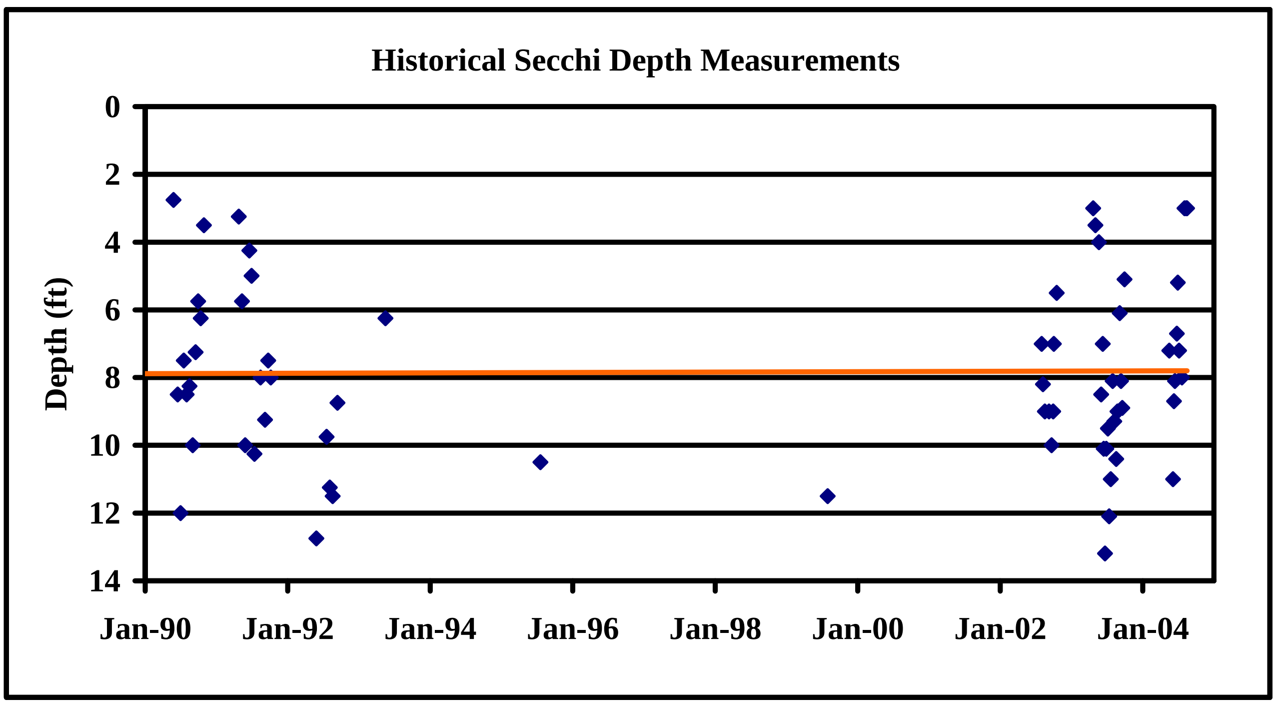

Figure 27. Historical Secchi disk transparency data for Holem Lake sampled by the Indian Clean Lakes Program, IDNR Division of Fish and Wildlife, and Indiana Clean Lakes Volunteer Monitoring Program.

The other parameters displayed in Table 19 do not show a trend. Plankton densities were variable for the years in which it was collected, making it difficult to discern any trends in water quality from this data. The highest plankton concentration was recorded in 1989. Since that time, plankton concentrations fluctuated from approximately 2,000 organisms/L to 20,000 organisms/L. Blue-green algae, which are typically associated with degraded water quality, comprised 54% to 93% of the plankton community during each of the surveys where plankton was collected. The Indiana TSI scores, which combine many of the individual parameters into a single index score, suggest the lake's water quality improved from 1989 to 1999 before declining to the level observed during the current study. The TSI scores of 41 and 39 from the 1970s and the current study, respectively, place the lake in the eutrophic category. Scores from the 1990s place the lake in the mesotrophic range.

Tables 20 through 22 and Figures 28 and 29 present the results of the most recent (excluding the current study) examinations of Holem Lake. The 1989, 1995, and 1999 temperature profiles (Figure 28) show that Holem Lake was stratified at the time of sampling and indicate a developed hypolimnion. In 1989, anoxic conditions did not occur within Holem Lake; however, below 16 feet (4.9 m) the water's dissolved oxygen concentration was very low. In 1995 and 1999, anoxic conditions existed below 20 feet (6.1 m; Figure 29). The 2003 dissolved oxygen profile illustrates a condition similar to that observed in Cook Lake in the 1970s, where a sharp increase in oxygen at 4 feet (1.2 m) creates a positive-heterograde profile. Increased photosynthesis by settling phytoplankton typically causes such a profile.

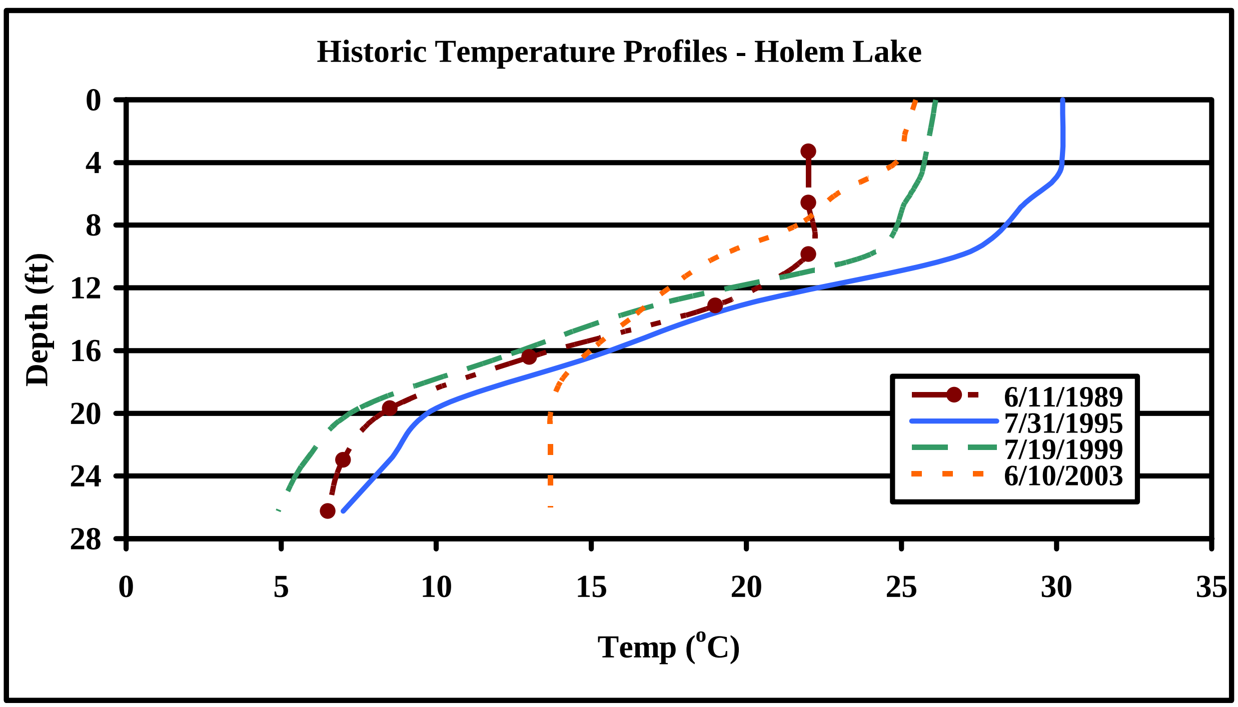

Figure 28. Historical temperature profiles for Holem Lake.
Source: CLP, 1989, 1995, and 1999; Robertson and Price, 2003.

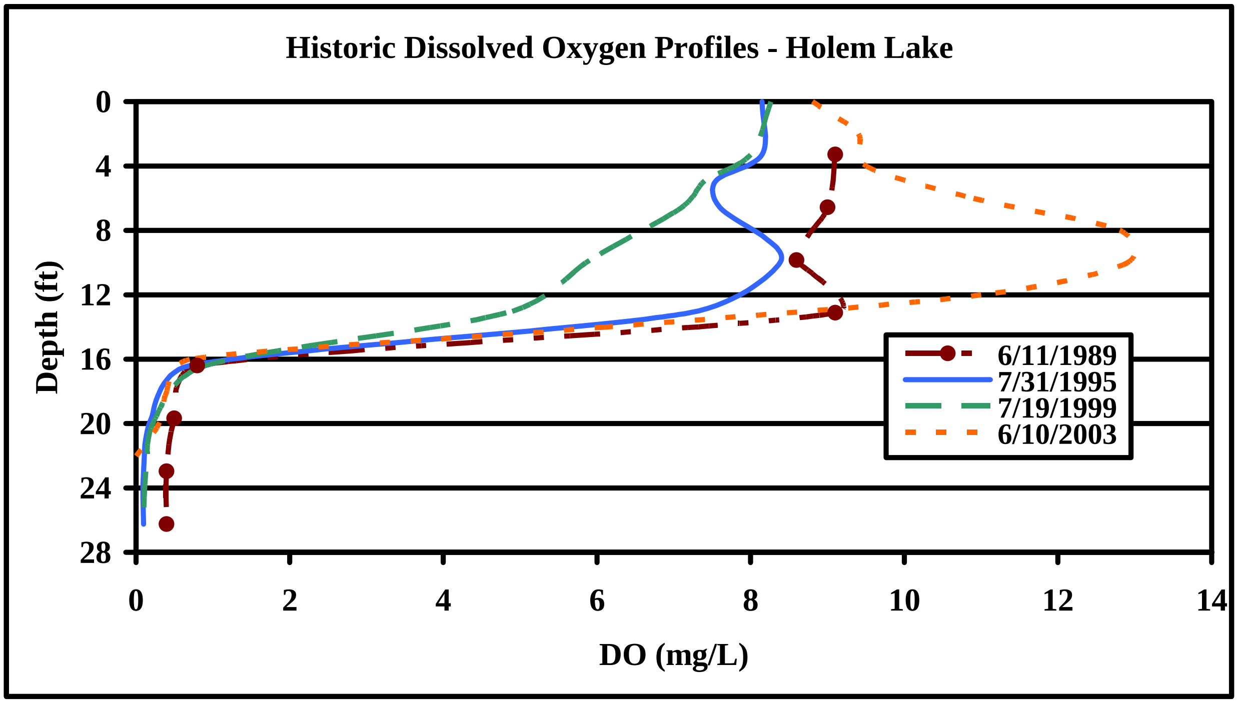

Figure29. Historical dissolved oxygen profiles for Holem Lake.
Source: CLP, 1989, 1995, and 1999; Robertson and Price, 2003.

In addition to the Secchi disk transparency depths, other parameters indicate that Holem Lake's water clarity changed little from 1989 to 1999. The amount of light that penetrated the lake's water column to a depth of three feet decreased from 47% in 1989 to a low of 25% in 1995 before increasing to a high of 55% in 1999. The lake's 1% light level, the level at which only 1% of surface light penetrates, did not change from 1995 to 1999 extending to a depth of 17 feet (5.2 m) during both surveys.

The nutrient data provide additional information about Holem Lake. While mean total phosphorus is variable for the three years as shown in Tables 20 to 22, the more detailed evaluations show that hypolimnetic total phosphorus concentrations are much higher than epilimnetic total phosphorus concentrations. The detailed evaluations also show that in 1989 and 1995 much of the total phosphorus was in the dissolved form of phosphorus (SRP). This indicates that the lake is releasing phosphorus from its bottom sediments. Additionally, Holem Lake exhibited high hypolimnetic ammonia concentrations, suggesting decomposition of organic matter is occurring in the lake's bottom waters. Nitrate levels were very high in 1989, but this were low during the 1995 and 1999 assessments. The Indiana TSI scores varied over the ten years. Generally, the Indiana TSI scores suggest that in 1989 Holem Lake was eutrophic, while the Indiana TSI scores in 1995 and 1999 suggest that the lake was mesotrophic.

Table 20. Historical water quality characteristics of Holem Lake, June 11, 1989.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
Secchi Depth Transparency	1.9 m	-	0
Light Transmission @ 3 ft.	47%	-	3
Total Phosphorous	0.026 mg/L	0.482 mg/L	4
Soluble Reactive Phosphorous	0.007 mg/L	0.397 mg/L	4
Nitrate-Nitrogen	0.412 mg/L	0.510 mg/L	2
Ammonia-Nitrogen	0.022 mg/L	5.145 mg/L	4
Organic Nitrogen	1.565 mg/L	-	3
Oxygen Saturation @ 5ft.	103%	-	0
% Water Column Oxic	75%	-	1
Plankton Density	94,487/L	-	10
Blue-Green Dominance	92.3%	-	10
		TSI Score	**41**

Table 21. Historical water quality characteristics of Holem Lake, July 31, 1995.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.45	6.37	-
Alkalinity	166 mg/L	234 mg/L	-
Conductivity	445 μmhos	385 μmhos	-
Secchi Depth Transparency	3.2 m	-	0
Light Transmission @ 3 ft.	25%	-	4
1% Light Level	17 ft	-	-
Total Phosphorous	0.013 mg/L	0.164 mg/L	3
Soluble Reactive Phosphorous	0.005 mg/L	0.075 mg/L	2
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.028 mg/L	2.308 mg/L	4
Organic Nitrogen	0.562 mg/L	1.165 mg/L	2
Oxygen Saturation @ 5ft.	99.9%	-	0
% Water Column Oxic	50%	-	2
Plankton Density	24,705/L	-	3
Blue-Green Dominance	79.5%	-	10
Chlorophyll *a*	2.26 μg/L	-	-
		TSI Score	**30**

Table 22. Historical water quality characteristics of Holem Lake, July 19, 1999.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.4	7.4	-
Alkalinity	156 mg/L	219 mg/L	-
Conductivity	432 μmhos	382 μmhos	-
Secchi Depth Transparency	3.5 m	-	0
Light Transmission @ 3 ft.	55%	-	2
1% Light Level	17 ft	-	-
Total Phosphorous	0.028 mg/L	0.207 mg/L	3
Soluble Reactive Phosphorous	0.014 mg/L	0.049 mg/L	1
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	0.876 mg/L	2
Organic Nitrogen	0.362 mg/L	1.668 mg/L	3
Oxygen Saturation @ 5ft.	90%	-	0
% Water Column Oxic	50%	-	2
Plankton Density	2,017/L	-	0
Blue-Green Dominance	53.9%	-	10
Chlorophyll *a*	3.36 μg/L	-	-
		TSI Score	**23**

3.2.3 Kreighbaum Lake

The Indiana Department of Natural Resources, Division of Fish and Wildlife, the Indiana State Pollution Control Board, volunteer monitors, and the Indiana Clean Lakes Program have conducted various water quality tests on Kreighbaum Lake. Table 23 presents a summary of some selected water quality parameters from these assessments of Kreighbaum Lake.

Based on some of the parameters in Table 23, Kreighbaum Lake's water quality may have worsened slightly over the past 35 years, but the decrease in quality has not been significant. There has been a gradual decrease in water clarity in Kreighbaum Lake over the past 35 years. In the 1970s, Secchi disk transparency depth measured 11 feet (3.4 m), the deepest transparency observed in Kreighbaum Lake. Secchi disk transparency depths ranged from 7.2 to 9.8 feet (2.2 to 3.0 m) from 1980 to 1995. In contrast, all Secchi disk transparency depths were below 7 feet (2.1 m) after 1995. Volunteer monitoring, Indiana Clean Lakes Program, and IDNR Division of Fish and Wildlife data indicates a decreasing trend in transparency. This trend should be viewed with caution due to seasonal variation and the collection of only limited data after 1993 (Figure 30). Volunteers conducted Secchi disk transparency readings from late March through to late October from 1990 to 1993; however, volunteers only completed transparency readings in early September 2003, which is when transparency is likely at its lowest. Total phosphorus concentration in Kreighbaum Lake's water column appears to have increased from the 1970s to the 1990s. Since 1995, total phosphorus concentrations have fluctuated. Total phosphorus concentrations exceeded the median concentration observed in Indiana lakes in 1991, 1995, and 2004 (current study). The percentage of the water column that contains oxygen has decreased over the past 25 years. In 1980, approximately 70% of the water column contained oxygen, providing ample habitat for the lake's inhabitants. (This percentage is likely higher than those observed during the 1990s because it was recorded earlier in the season.) Since 1980, the percentage of the water column with oxygen decreased to a range of 40% to 50%. Finally, the Indiana TSI scores decreased from the 1970s to the 1990s. Since 1991, Indiana TSI scores have fluctuated, but remain generally similar. The score from the 1970s suggests that Kreighbaum Lake is eutrophic, while the scores from the 1990s and the current assessments suggest the lake is mesotrophic to eutrophic. Since the Indiana TSI score relies heavily on the plankton community, the variation in TSI scores observed are likely due corresponding variations in plankton densities present in Kreighbaum Lake.

Table 23. Summary of historic data for Kreighbaum Lake.

Date	Secchi (ft)	Percent Oxic (%)	Mean TP (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Data Source
1970s	11.0	--	0.07*	--	42[§]	IDEM, 1986
7/8/1980	7.6	71%	--	--	--	Rowe, 1981
1990[cs]	9.6	--	--	--	--	Volunteer Monitor, 1990
1991[cs]	7.5	--	--	--	--	Volunteer Monitor, 1991
8/20/1991	7.2	40%	0.280	5,537	25	CLP, 1991
1992[cs]	8.3	--	--	--	--	Volunteer Monitor, 1992
7/19/1995	9.8	40%	0.206	28,018	35	CLP, 1995
7/31/1999	6.9	50%	0.121	4,962	25	CLP, 1999
6/4/2003	5.6	47%	--	--	--	Price, 2004
2004	6.9	40%	0.209	4,222	30	Current Study

* Water column average; all other values are mean of epilimnion and hypolimnion values.
[§] Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.
[cs]Volunteer monitoring data collected through the Indiana Clean Lakes Volunteer Monitoring Program. Data displayed in the table represent median values for data collected annually during July and August.

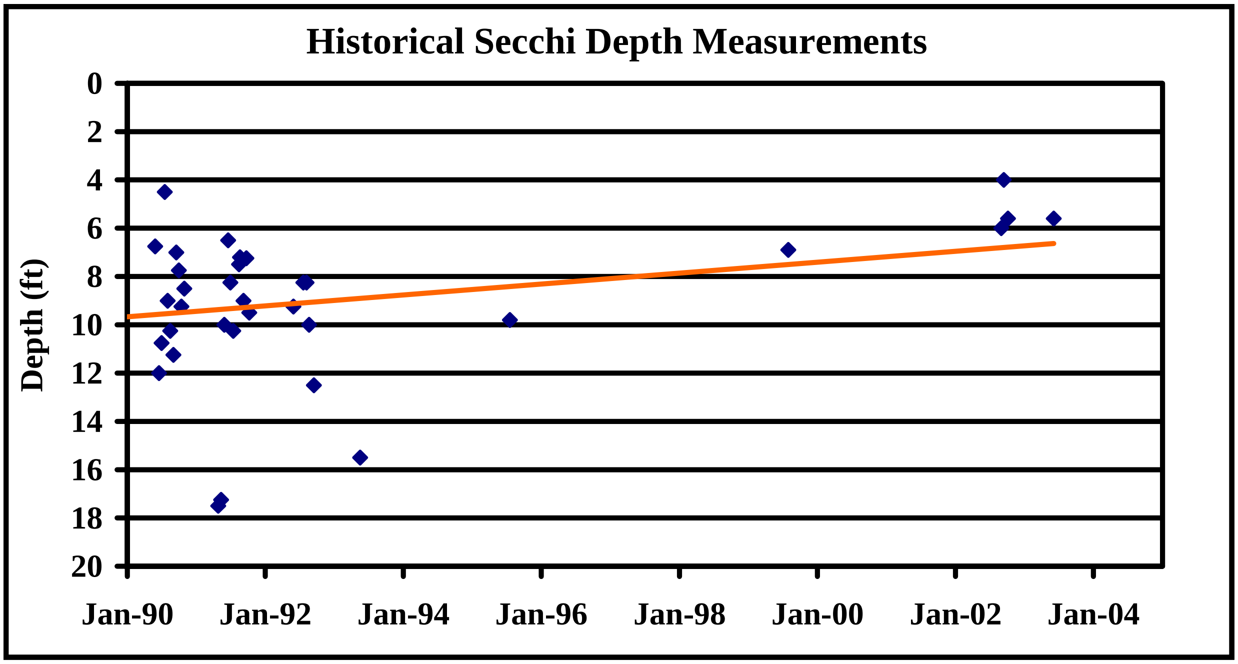

Figure 30. Historical Secchi disk transparency data for Kreighbaum Lake sampled by the Indiana Clean Lakes Program, IDNR Division of Fish and Wildlife, and Indiana Clean Lakes Program Volunteer Monitoring Program.

Historical dissolved oxygen and temperature profiles from the 1991, 1995, and 1999 Clean Lakes Program and the 1980 and 2003 IDNR, Division of Fish and Wildlife assessments of Kreighbaum Lake are displayed in Figures 31 and 32. The dissolved oxygen profiles reiterate the data summarized in Table 23. The profiles show that one-third to one-half of lake's water column was anoxic. The 1995 profile is negative-heterograde, which is characterized by a drop in oxygen concentration at a depth below the water surface. This is likely associated with increased respiration by bacteria in the metalimnion as they decompose settling phytoplankton. Called a ***metalimnetic oxygen minimum***, this decline in dissolved oxygen results when the rate of decomposition of phytoplankton and other organic matter exceeds the rate of oxygen supplied by photosynthesis.

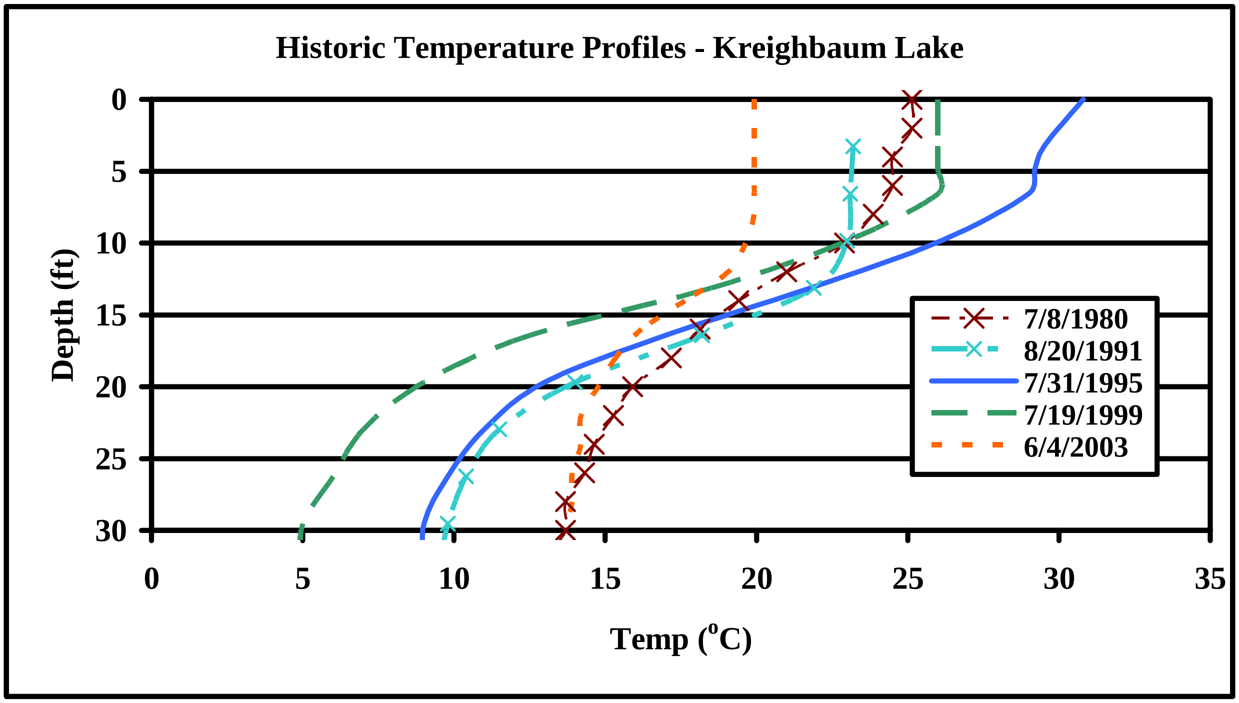

Figure 31. Historical temperature profiles for Kreighbaum Lake.
Source: Rowe, 1981; CLP, 1991, 1995, and 1999; Price, 2004.

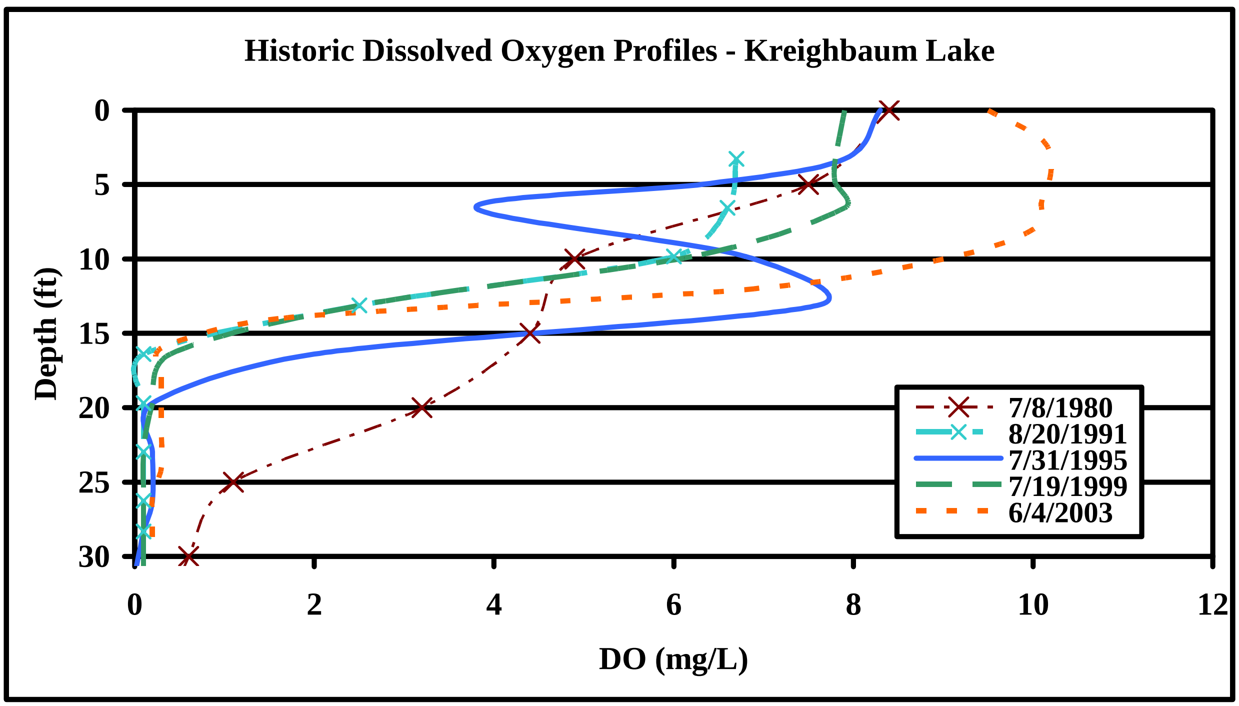

Figure 32. Historical dissolved oxygen profiles for Kreighbaum Lake.
Source: Rowe, 1981; CLP, 1991, 1995, and 1999; Price, 2004.

Because of the comprehensive nature of the Clean Lakes Program assessments, it may be useful to provide the complete results of previous CLP examinations of Kreighbaum Lake for comparison to the current study's results. Tables 24 through 26 outline those results. In the 1990s, Kreighbaum Lake's Secchi disk transparency depth ranged from 6.2 to 6.8 feet (1.9 to 2.1 m). Light transmission at 3 feet (0.9 m) was less than 35% in 1991 and 1995, but increased to greater than 70% in 1999. During the 1990s, the 1% light level increased from 14 feet (4.3m) in 1991 to 18 feet (5.4 m) in 1995 before declining again in 1999 (16 feet or 4.9 m). During the same period, less than 50% of the water column contained oxygen levels above 0.3 mg/L. The lack of oxygen limits habitat availability for the lake's biota and creates conditions conducive for the release of phosphorus from the lake's bottom sediments.

The lake assessments also indicate that Kreighbaum Lake possesses relatively high nutrient concentrations. Hypolimnetic soluble reactive phosphorus concentrations are particularly high, accounting for the vast majority of the total phosphorus concentration each year. The high level of dissolved phosphorus coupled with anoxic conditions suggests internal phosphorus release is likely occurring in Kreighbaum Lake. The lake also exhibits high hypolimnetic ammonia concentrations. Because ammonia is a by-product of decomposition, high hypolimnetic ammonia concentrations usually indicate that decomposition of organic materials is occurring in the lake's bottom waters. High ammonia concentrations can also create inhospitable conditions for the lake's biota.

Tables 25 and 26 show that in 1995 and 1999 Kreighbaum Lake supported an algal community dominated by blue-green algae. Blue-green algae are considered nuisance algae and generally dominate the algal community in eutrophic lakes. Kreighbaum Lake's historical data indicate that the lake is mesotrophic to eutrophic, so a dominance of blue-green algae is not unexpected.

Table 24. Historical water quality characteristics of Kreighbaum Lake, August 20, 1991.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	7.7	7.0	-
Alkalinity	159 mg/L	200 mg/L	-
Conductivity	360 μmhos	340 μmhos	-
Secchi Depth Transparency	2.2 m	-	0
Light Transmission @ 3 ft.	32%	-	3
1% Light Level	14 ft	-	-
Total Phosphorous	0.032 mg/L	0.524 mg/L	4
Soluble Reactive Phosphorous	0.005 mg/L	0.471 mg/L	4
Nitrate-Nitrogen	0.466 mg/L	0.425 mg/L	2
Ammonia-Nitrogen	0.030 mg/L	3.178 mg/L	4
Organic Nitrogen	1.161 mg/L	6.075 mg/L	5
Oxygen Saturation @ 5ft.	76.9%	-	0
% Water Column Oxic	40%	-	3
Plankton Density	5,537/L	-	1
Blue-Green Dominance	28.2%	-	0
		TSI Score	**25**

Table 25. Historical water quality characteristics of Kreighbaum Lake, July 31, 1995.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.15	7.20	-
Alkalinity	149 mg/L	207 mg/L	-
Conductivity	390 μmhos	325 μmhos	-
Secchi Depth Transparency	3.0 m	-	0
Light Transmission @ 3 ft.	24%	-	4
1% Light Level	18 ft	-	-
Total Phosphorous	0.010 mg/L	0.403 mg/L	4
Soluble Reactive Phosphorous	0.005 mg/L	0.343 mg/L	3
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.029 mg/L	2.225 mg/L	4
Organic Nitrogen	0.571 mg/L	1.538 mg/L	3
Oxygen Saturation @ 5ft.	83.5%	-	0
% Water Column Oxic	40%	-	3
Plankton Density	28,018/L	-	4
Blue-Green Dominance	85%	-	10
Chlorophyll *a*	3.74 μg/L	-	-
		TSI Score	**35**

Table 26. Historical water quality characteristics of Kreighbaum Lake, July 19, 1999.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.2	7.3	-
Alkalinity	130 mg/L	191 mg/L	-
Conductivity	400 μmhos	320 μmhos	-
Secchi Depth Transparency	2.1 m	-	0
Light Transmission @ 3 ft.	72%	-	0
1% Light Level	16 ft	-	-
Total Phosphorous	0.063 mg/L	0.178 mg/L	3
Soluble Reactive Phosphorous	0.012 mg/L	0.264 mg/L	3
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.033 mg/L	1.880 mg/L	3
Organic Nitrogen	0.910 mg/L	1.619 mg/L	3
Oxygen Saturation @ 5ft.	96%	-	0
% Water Column Oxic	50%	-	2
Plankton Density	4,963/L	-	1
Blue-Green Dominance	57.5%	-	10
Chlorophyll *a*	4.95 μg/L	-	-
		TSI Score	**25**

3.2.4 Millpond Lake

There have been few water quality evaluations completed on Millpond Lake. The Indiana State Pollution Control Board, volunteer monitors, and the Indiana Clean Lakes Program have conducted various water quality tests on Millpond Lake. Table 27 presents a summary of some selected water quality parameters from these assessments of Millpond Lake Lake.

Table 27. Summary of historic data for Millpond Lake.

Date	Secchi (ft)	Percent Oxic (%)	Mean TP (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Data Source
1970s	5.0	--	0.06*	--	58[§]	IDEM, 1986
1989	3.3	40%	0.102	24,414	26	CLP, 1989
1990	8.8[cs]	--	--	--	--	Volunteer Monitor, 1990
1991	6.8[cs]	--	--	--	--	Volunteer Monitor, 1991
1992	9.0[cs]	--	--	--	--	Volunteer Monitor, 1992
7/31/1995	1.6	75%	0.138	385,144	54	CLP, 1995
7/19/1999	4.3	25%	0.061	9,154	22	CLP, 1999
8/11/2004	5.6	75%	0.053	9,422	21	Current Study

* Water column average; all other values are mean of epilimnion and hypolimnion values.
[§] Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.
[cs]Volunteer monitoring data collected through the Indiana Clean Lakes Volunteer Monitoring Program. Data displayed in the table represent median values for data collected annually during July and August.

Based on the parameters in Table 27, Millpond Lake's water quality appears to have fluctuated, but ultimately, changed little when compared to the 1970s and current data. The Indiana State Pollution Control Board (IDEM, 1986) recorded a Secchi disk depth of 5 feet (1.5 m) in the 1970s. Secchi disk transparency generally increased from the 1970s to the early 1990s, when Secchi disk depths ranged from 6.8 to 9.0 feet (2.1 to 2.7 m). Transparency measured 1.6 feet (0.5 m) in 1995, the poorest transparency recorded at Millpond Lake. Transparency improved over the next 10 years with Secchi disk transparency depths greater than 5.5 feet (1.7 m) recorded during the current survey. Figure 33 demonstrates the seasonal and long term variability associated with Secchi disk transparency. The decreasing trend in Secchi disk transparency displayed in Figure 33 should be viewed with caution due to the limited collection of data after 1992. Total phosphorus concentrations in Millpond Lake increased from 1970 to 1995 before declining in 1999 to levels similar to those observed in the 1970s. The percentage of the water column that contains sufficient oxygen to support aquatic biota has also fluctuated. In 1999, only 25% of Millpond Lake's water column contained oxygen. Approximately 75% of the water column contained sufficient oxygen in 1995 and 2004.

Consistent with many of the parameters shown in Table 27, the Indiana TSI scores for Millpond Lake have fluctuated over the past 35 years. The Indiana TSI scores for Millpond Lake decreased from the initial lake assessment in the 1970s to the more recent assessment in 1989. In 1995, the highest TSI score observed at Millpond Lake was recorded. In the 1970s the TSI score of 58 indicated that the lake was hypereutrophic. The drop in TSI score to 26 in 1989 suggests the lake's productivity decreased greatly. Conversely, the algae bloom and resultant TSI score of 54 observed in 1995 suggests that the lake was again hypereutrophic. The 1999 and 2004 TSI scores place the lake in the mesotrophic category. The variation in trophic state category from mesotrophic to hypereutrophic and vice-versa is likely based on algal blooms at the time of the sampling rather than a true change in lake productivity. For example, the plankton community present during the 1995 assessment added 27 to 28 points to the TSI resulting in a relatively high TSI score. The Indiana TSI relies heavily on the algal community; therefore, the high density algal community and the blue-green dominance resulted in a score nearly double that observed during previous and future Clean Lakes Program assessments.

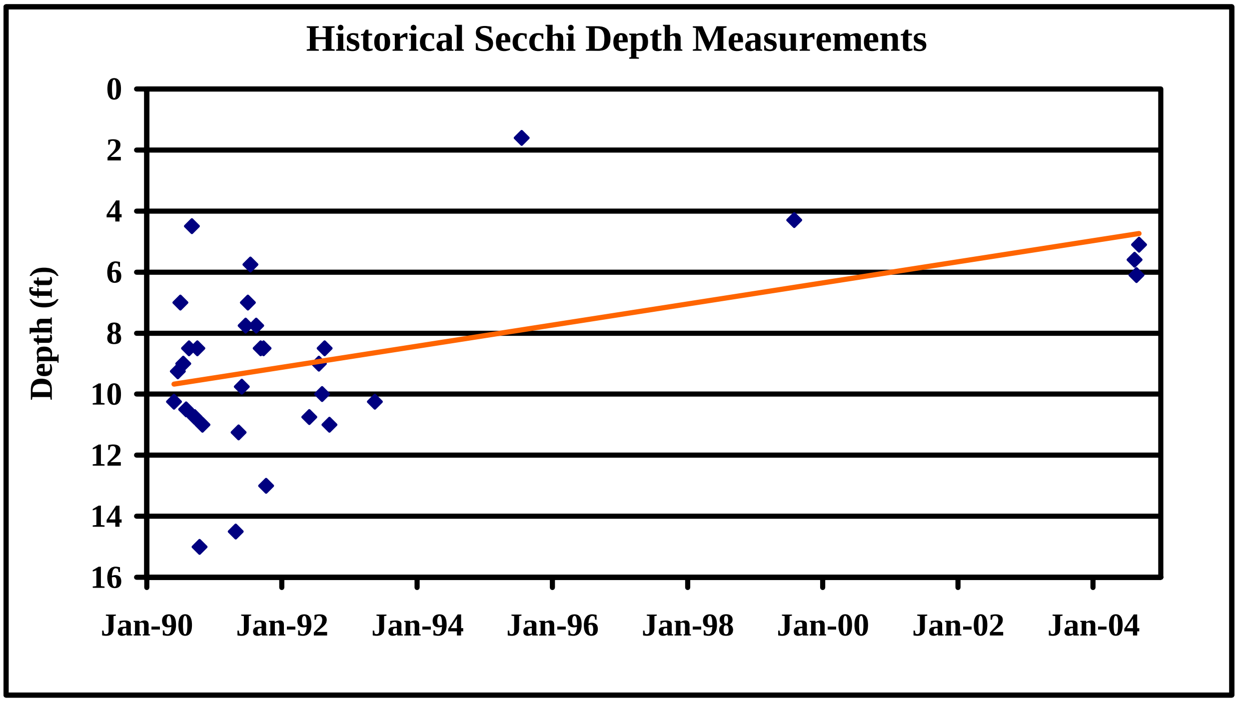

Figure 33. Historical Secchi depth transparency data for Millpond Lake sampled by the Indiana Clean Lakes Program, IDNR Division of Fish and Wildlife, and Indiana Clean Lakes Program Volunteer Monitoring Program.

Tables 28 through 30 and Figure 34 present the results from the most recent (excluding the current study) comprehensive examinations of Millpond Lake. The data indicate that in 1995 water quality conditions were poor and Millpond Lake was best described as a eutrophic to hypereutrophic lake. In 1995, only 25% of the water column was oxygenated. Figure 34 shows that there was virtually no oxygen in the water below 5 feet (1.5 m) in 1995. Water clarity was also poor in 1995. Secchi disk transparency depth was only 1.6 feet (0.5 m). Only 2% of the incident light reached a water depth of 3.3 feet (1.0 m). In clearer lakes, light transmission at 3 feet can be expected to exceed 50%. By a depth of 3 feet (0.9 m), light had been extinguished to the point where photosynthesis could not be supported. This limits the habitat availability for rooted plants. The data show that in 1995, Millpond Lake supported a dense algal population. The concentration of chlorophyll *a* was very high, approximately 85 μg/L. Chlorophyll *a* concentrations of this magnitude are usually characteristic of hypereutrophic lakes. Blue-green algae, a nuisance algae associated with productive lakes, dominated the Millpond Lake algal community. The densest plankton population (385,144 organisms/L) observed in Millpond Lake occurred in 1995. Combined, this data suggest that Millpond Lake exhibited characteristics of a hypereutrophic lake at the time of the 1995 sampling.

The data from the 1989 and 1999 sampling events suggest conditions in Millpond Lake differed significantly from conditions observed in 1995. In 1989 and 1999, water quality characteristics indicate that Millpond Lake is mesotrophic in nature. In 1999, nearly 75% of the water column was oxygenated. Water clarity was also better in 1989 and 1999 compared to 1995. Secchi disk transparency depth was approximately 3.3 feet (1.0 m) in 1989 and 4.3 feet (1.3 m) in 1999. Approximately 25% of the incident light reached a water depth of 3 feet (0.9 m) in both years. The littoral zone, or area available for rooted plant growth, extended to a depth of 10 feet (3.1 m) in 1999. The concentration of chlorophyll *a* in 1999 was elevated, but was approximately five times lower than the concentration observed in 1995. Blue-green algae were not the dominant component of the lake's plankton community at the time of the 1999 sampling. These data suggest that Millpond Lake may be more mesotrophic in nature and that the 1995 sampling coincided with a severe algae bloom that may not necessarily be representative of the nature of Millpond Lake.

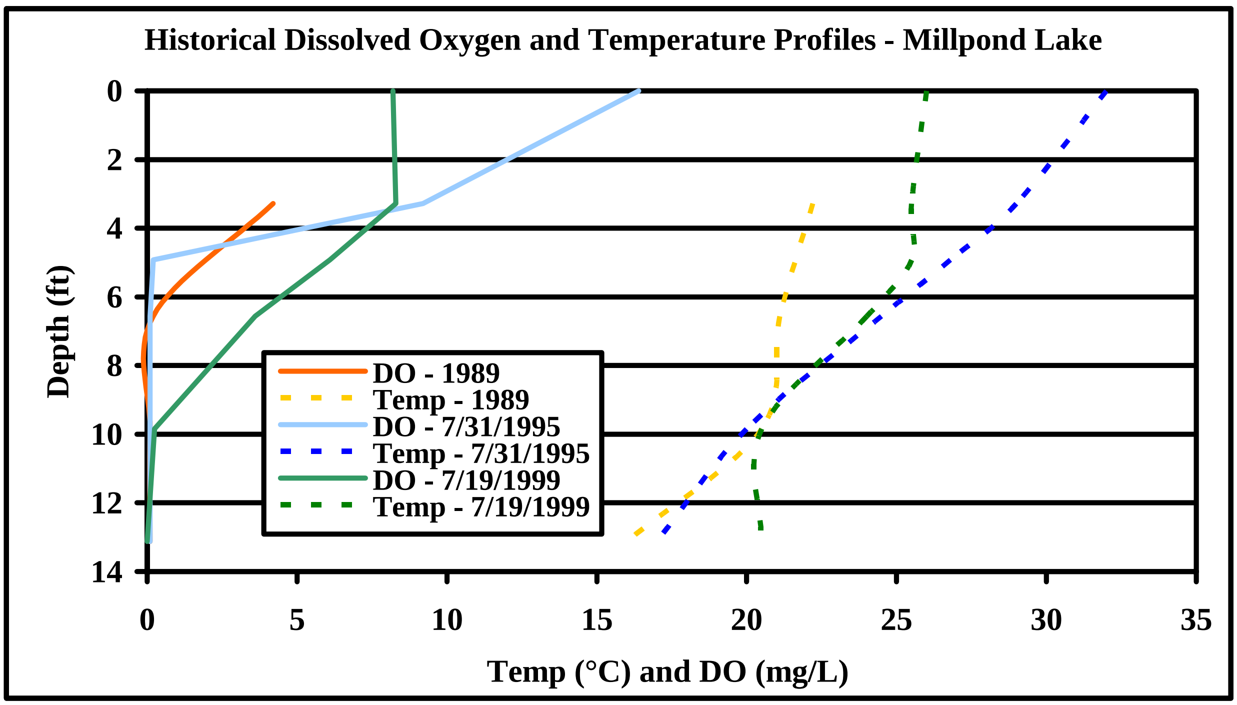

Figure 34. Historical dissolved oxygen and temperature profiles for Millpond Lake.
Source: CLP, 1989, 1995 and 1999.

Table 28. Historical water quality characteristics of Millpond Lake, summer 1989.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
Secchi Depth Transparency	1.0 m	-	6
Light Transmission @ 3 ft.	28%	-	4
Total Phosphorous	0.076 mg/L	0.128 mg/L	3
Soluble Reactive Phosphorous	0.010 mg/L	0.037 mg/L	0
Nitrate-Nitrogen	1.170 mg/L	1.016 mg/L	3
Ammonia-Nitrogen	0.030 mg/L	0.574 mg/L	1
Organic Nitrogen	1.389 mg/L	1.639 mg/L	3
Oxygen Saturation @ 5ft.	60%	-	0
% Water Column Oxic	40%	-	3
Plankton Density	24,414/L	-	3
Blue-Green Dominance	6.3	-	0
		TSI Score	**26**

Table 29. Historical water quality characteristics of Millpond Lake, July 31, 1995.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	7.75	7.25	-
Alkalinity	156 mg/L	172 mg/L	-
Conductivity	420 μmhos	345 μmhos	-
Secchi Depth Transparency	0.5 m	-	6
Light Transmission @ 3 ft.	2%	-	4
1% Light Level	3.3 ft	-	-
Total Phosphorous	0.129 mg/L	0.146 mg/L	3
Soluble Reactive Phosphorous	0.005 mg/L	0.082 mg/L	2
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	2
Ammonia-Nitrogen	0.033 mg/L	1.386 mg/L	0
Organic Nitrogen	2.192 mg/L	0.928 mg/L	3
Oxygen Saturation @ 5ft.	2.5%	-	3
% Water Column Oxic	75%	-	1
Plankton Density	385,144/L	-	20
Blue-Green Dominance	89.8%	-	10
Chlorophyll *a*	84.7 μg/L	-	-
		TSI Score	**54**

Table 30. Historical water quality characteristics of Millpond Lake, July 19, 1999.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.0	7.3	-
Alkalinity	150 mg/L	149 mg/L	-
Conductivity	390 μmhos	355 μmhos	-
Secchi Depth Transparency	1.3 m	-	6
Light Transmission @ 3 ft.	22%	-	4
1% Light Level	10 ft	-	-
Total Phosphorous	0.043 mg/L	0.078 mg/L	3
Soluble Reactive Phosphorous	0.010 mg/L	0.010 mg/L	0
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	0.018 mg/L	0
Organic Nitrogen	1.368 mg/L	1.356 mg/L	3
Oxygen Saturation @ 5ft.	75%	-	0
% Water Column Oxic	25%	-	4
Plankton Density	9,154/L	-	2
Blue-Green Dominance	24.8%	-	0
Chlorophyll *a*	17.55 μg/L	-	-
		TSI Score	**22**

3.3 Lake Assessment Methods

The water sampling and analytical methods used for the Four Lakes study were consistent with those used in IDEM's Indiana Clean Lakes Program and IDNR's Lake and River Enhancement Program. Water samples were collected and analyzed for various parameters from Cook, Holem, Kreighbaum, and Millpond Lakes on August 11, 2004 from the surface waters (***epilimnion***) and from the bottom waters (***hypolimnion***) of each of the lakes at a location over the deepest water. The parameters include conductivity, total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, and organic nitrogen. In addition to these parameters, several other measurements of lake health were recorded. Secchi disk, light transmission, and oxygen saturation are single measurements made in the epilimnion. Chlorophyll was determined only for an epilimnetic sample. Dissolved oxygen and temperature were measured at one-meter intervals from the surface to the bottom. A tow to collect plankton was made from the 1% light level depth up to the water surface. Conductivity, temperature, and dissolved oxygen were measured *in situ* with an YSI Model 85 meter.

Water samples were also collected and analyzed for various parameters from the culvert connecting Cook and Millpond Lakes. (Water was not flowing from Myers to Cook Lake during the sampling event; therefore, no samples were collected from this culvert.) The culvert water samples were analyzed for conductivity, total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, organic nitrogen, total suspended solids, and turbidity. Conductivity, temperature, and dissolved oxygen were measured *in situ* with an YSI Model 85 meter. Water velocity through the culvert was measured using a Marsh-McBirney Flo-Mate current meter. The cross-sectional area of the culvert was measured and discharge calculated by multiplying water velocity by the cross-sectional area.

All water chemistry samples were placed in the appropriate bottle (with preservative if needed) and stored in an ice chest until analysis at SPEA's laboratory in Bloomington. SRP samples were filtered in the field through a Whatman GF-C filter.

All sampling techniques and laboratory analytical methods were performed in accordance with procedures in *Standard Methods for the Examination of Water and Wastewater*, 20th Edition (APHA, 1998). Plankton counts were made using a standard Sedgewick-Rafter counting cell. Fifteen fields per cell were counted. Plankton identifications were made according to: Prescott (1982), Ward and Whipple (1959), Wehr and Sheath (2003), and Whitford and Schumacher (1984).

The following is a brief description of the parameters analyzed during the sampling efforts:

Temperature. Temperature can determine the form, solubility, and toxicity of a broad range of aqueous compounds. For example, water temperature affects the amount of oxygen dissolved in the water column. Likewise, life associated with the aquatic environment in any location has its species composition and activity regulated by water temperature. Since essentially all aquatic organisms are 'cold-blooded,' the temperature of the water regulates their metabolism and ability to survive and reproduce effectively (USEPA, 1976). The Indiana Administrative Code (327 IAC 2-1-6) sets maximum temperature limits to protect aquatic life for Indiana waters. For example, temperatures during the summer months should not exceed 90 ^{o}F (32.2 ^{o}C).

Dissolved Oxygen (DO). DO is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3-5 mg/L of DO. Coldwater fish such as trout generally require higher concentrations of DO than warmwater fish such as bass or bluegill. The IAC sets minimum DO concentrations at 4 mg/L for warmwater fish, but all waters must have a daily average of 5 mg/L. DO enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth can over-saturate (greater than 100% saturation) the water with DO. Conversely, dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

Conductivity. Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions: on their total concentration, mobility, and valence (APHA, 1998). Rather than setting a conductivity standard, the Indiana Administrative Code sets a standard for dissolved solids (750 mg/L). Multiplying a dissolved solids concentration by a conversion factor of 0.55 to 0.75 µmhos per mg/L of dissolved solids roughly converts a dissolved solids concentration to specific conductance (Allan, 1995). Thus, converting the IAC dissolved solids concentration standard to specific conductance by multiplying 750 mg/L by 0.55 to 0.75 µmhos per mg/L yields a specific conductance range of approximately 1000 to 1360 µmhos. This report presents conductivity measurements at each site in µmhos.

Nutrients. Limnologists measure nutrients to predict the amount of algae growth and/or rooted plant (macrophyte) growth that is possible in a lake or stream. Algae and rooted plants are a natural and necessary part of aquatic ecosystems. Both will always occur in a healthy lake or stream. Complete elimination of algae and/or rooted plants is neither desirable nor even possible and should, therefore, never be the goal in managing a lake or stream. Algae and rooted plant growth can, however, reach nuisance levels and interfere with the aesthetic and recreational uses of a lake or stream. Limnologists commonly measure nutrient concentrations in aquatic ecosystem evaluations to determine the potential for such nuisance growth.

Like terrestrial plants, algae and rooted aquatic plants rely primarily on phosphorus and nitrogen for growth. Aquatic plants receive these nutrients from fertilizers, human and animal waste, atmospheric deposition in rainwater, and yard waste or other organic material that reaches the lake or stream. Nitrogen can also diffuse from the air into the water. This nitrogen is then "fixed" by certain algae species into a usable, "edible" form of nitrogen. Because of this readily available source of nitrogen (the air), phosphorus is usually the "limiting nutrient" in aquatic ecosystems. This means that it is actually the amount of phosphorus that controls plant growth in a lake or stream.

Phosphorus and nitrogen have several forms in water. The two common phosphorus forms are **soluble reactive phosphorus (SRP)** and **total phosphorus (TP)**. SRP is the dissolved form of phosphorus. It is the form that is "usable" by algae. Algae cannot directly digest and use particulate phosphorus. Total phosphorus is a measure of both dissolved and particulate forms of phosphorus. The most commonly measured nitrogen forms are **nitrate-nitrogen (NO_3)**, **ammonium-nitrogen (NH_4^+)**, and **total Kjeldahl nitrogen (TKN)**. Nitrate is a dissolved form of nitrogen that is commonly found in the upper layers of a lake or anywhere that oxygen is readily available. In contrast, ammonium-nitrogen is generally found where oxygen is lacking. Ammonium is a byproduct of decomposition generated by bacteria as they decompose organic material. Like SRP, ammonium is a dissolved form of nitrogen and the one utilized by algae for growth. The TKN measurement parallels the TP measurement to some extent. TKN is a measure of the **total organic nitrogen** (particulate) and ammonium-nitrogen in the water sample.

While the United States Environmental Protection Agency (USEPA) has established some nutrient standards for drinking water safety, it has not established similar nutrient standards for protecting the biological integrity of a lake. (The USEPA, in conjunction with the States, is currently working on developing these standards.) The USEPA has issued recommendations for numeric nutrient criteria for lakes in Aggregate Nutrient Ecoregion VI, within which Cook, Holem, Kreighbaum, and Millpond Lakes lie (USEPA, 2000a). While these are not part of the Indiana Administrative Code, they serve as potential target conditions for which lake managers might aim. Other researchers have suggested thresholds for several nutrients in lake ecosystems as well (Carlson, 1977; Vollenweider, 1975). Lastly, the Indiana Administrative Code (IAC) requires that all waters of the state have a nitrate concentration of less than 10 mg/L, which is the drinking water standard for the state.

With respect to lakes, limnologists have determined the existence of certain thresholds for nutrients above which changes in the lake's biological integrity can be expected. For example, Correll (1998) found that soluble reactive phosphorus concentrations of 0.005 mg/L are enough to maintain eutrophic or highly productive conditions in lake systems. For total phosphorus concentrations, 0.03 mg/L (0.03 ppm – parts per million or 30 ppb – parts per billion) is the generally accepted threshold. Total phosphorus concentrations above this level can promote nuisance algae blooms in lakes. The USEPA's recommended nutrient criterion for total phosphorus is fairly low for Indiana lakes, 37.5 μg/L (USEPA, 2000a), but exceeds the generally accepted threshold established by Correll (1998). The USEPA suggested target is likely an unrealistic target for many Indiana lakes in this area as the suggested target is lower than the average (66 μg/L) for the ecoregion in which the Four Lakes lie (Indiana Clean Lakes Program data files, unpublished). Similarly, the USEPA's recommended nutrient criterion for nitrate-nitrogen in lakes is low at 16 μg/L. This is below the detection limit of most laboratories. In general, levels of inorganic nitrogen (which includes nitrate-nitrogen) that exceed 0.3 mg/L may also promote algae blooms in lakes. High levels of nitrate-nitrogen can be lethal to fish. The nitrate LC_{50} is 5 mg/L for logperch, 40 mg/L for carp, and 100 mg/L for white sucker. (Determined by performing a bioassay in the laboratory, the LC_{50} is the concentration of the pollutant being tested, in this case nitrogen, at which 50% of the test population died in the bioassay.) The USEPA's recommended criterion for total Kjeldahl nitrogen in lakes in Nutrient Ecoregion VI is 0.765 mg/L.

It is important to remember that none of the threshold or recommended concentrations listed above are state standards for water quality. They are presented here to provide a frame of reference for the concentrations found in Cook, Holem, Kreighbaum, and Millpond Lakes. The IAC sets only nitrate-nitrogen and ammonia-nitrogen standards for waterbodies in Indiana. The Indiana Administrative Code requires that all waters of the state have a nitrate-nitrogen concentration of less than 10 mg/L, which is the drinking water standard for the state. The IAC standard for ammonia-nitrogen depends upon the water's pH and temperature, since both can affect ammonia-nitrogen's toxicity. None of the Four Lakes samples exceeded the state standard for either nitrate-nitrogen or ammonia-nitrogen.

Turbidity. Turbidity (measured in Nephelometric Turbidity Units) is a measure of particles suspended in the water itself. It is generally related to suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms.

Total Suspended Solids (TSS). A TSS measurement quantifies all particles suspended and dissolved in water. Closely related to turbidity, this parameter quantifies sediment particles and other solid compounds typically found in water. In general, the concentration of suspended solids is greater following storm events due to increased overland flow. The increased overland flow erodes and carries more soil and other particulates to the lake. The sediment in water originates from many sources, but a large portion of sediment entering waterbodies comes from active construction sites or other disturbed areas such as unvegetated stream banks and poorly managed farm fields.

Suspended solids impact streams and lakes in a variety of ways. When suspended in the water column, solids can clog the gills of fish and invertebrates. As the sediment settles to the stream or lake bottom, it covers spawning and resting habitat for aquatic fauna, reducing the animals' reproductive success. Suspended sediments also impair the aesthetic and recreational value of a waterbody. Few people are enthusiastic about having a picnic near a muddy creek or lake.

Pollutants attached to sediment also degrade water quality. In general, TSS concentrations greater than 80 mg/L have been found to be deleterious to aquatic life (Waters, 1995).

Secchi Disk Transparency. This refers to the depth to which the black and white Secchi disk can be seen in the lake water. Water clarity, as determined by a Secchi disk, is affected by two primary factors: algae and suspended particulate matter. Particulates (for example, soil or dead leaves) may be introduced into the water by either runoff from the land or from sediments already on the bottom of the lake. Many processes may introduce sediments from runoff; examples include erosion from construction sites, agricultural land, and unvegetated riverbanks. Bottom sediments may be resuspended by bottom feeding fish such as carp, or in shallow lakes, by motorboats or strong winds. In general, lakes possessing Secchi disk transparency depths greater than 15 feet (4.5 m) have outstanding clarity. Lakes with Secchi disk transparency depths less than 5 feet (1.5 m) possess poor water clarity (ISPCB, 1976; Carlson, 1977). The USEPA recommended a numeric criterion of 4.6 feet (1.4 m) for Secchi disk depth in lakes (USEPA, 2000a).

Light Transmission. Similar to the Secchi disk transparency, this measurement uses a light meter (photocell) to determine the rate at which light transmission is diminished in the upper portion of the lake's water column. Another important light transmission measurement is determination of the 1% light level. The 1% light level is the water depth to which one percent of the surface light penetrates. This is considered the lower limit of plant growth in lakes. The volume of water above the 1% light level is referred to as the ***photic zone***.

Plankton. Plankton are important members of the aquatic food web. Plankton include the algae (microscopic plants) and the zooplankton (tiny shrimp-like animals that eat algae). Plankton are collected by towing a net with a very fine mesh (63-micron openings = 63/1000 millimeter) up through the lake's water column from the one percent light level to the surface. Of the many different planktonic species present in the water, the blue-green algae are of particular interest. Blue-green algae are those that most often form nuisance blooms and their dominance in lakes may indicate poor water conditions.

Chlorophyll *a*. The plant pigments in algae consist of the chlorophylls (green color) and carotenoids (yellow color). Chlorophyll *a* is by far the most dominant chlorophyll pigment and occurs in great abundance. Thus, chlorophyll *a* is often used as a direct estimate of algal biomass. In general, chlorophyll *a* concentrations below 2 μg/L are considered low, while those exceeding 10 μg/L are considered high and indicative of poorer water quality. The USEPA recommended a numeric criterion of 8.6 μg/L as a target concentration for lakes in Aggregate Nutrient Ecoregion VI (USEPA, 2000a). The recommended nutrient criterion is relatively high and represents data from only 224 lakes throughout the entire Aggregate Nutrient Ecoregion. The 25th percentile (2.6 μg/L) for the ecoregion in which the Four Lakes lie (Indiana Clean Lakes Program data files, unpublished) or Vollenweider's median concentration measured in mesotrophic lakes (4.7 μg/L) likely provide better targets for the Four Lakes.

3.3 Lake Assessment Results

3.3.1 Cook Lake

Results from the Cook Lake water quality assessment are included in Figure 35 and Tables 31 and 32.

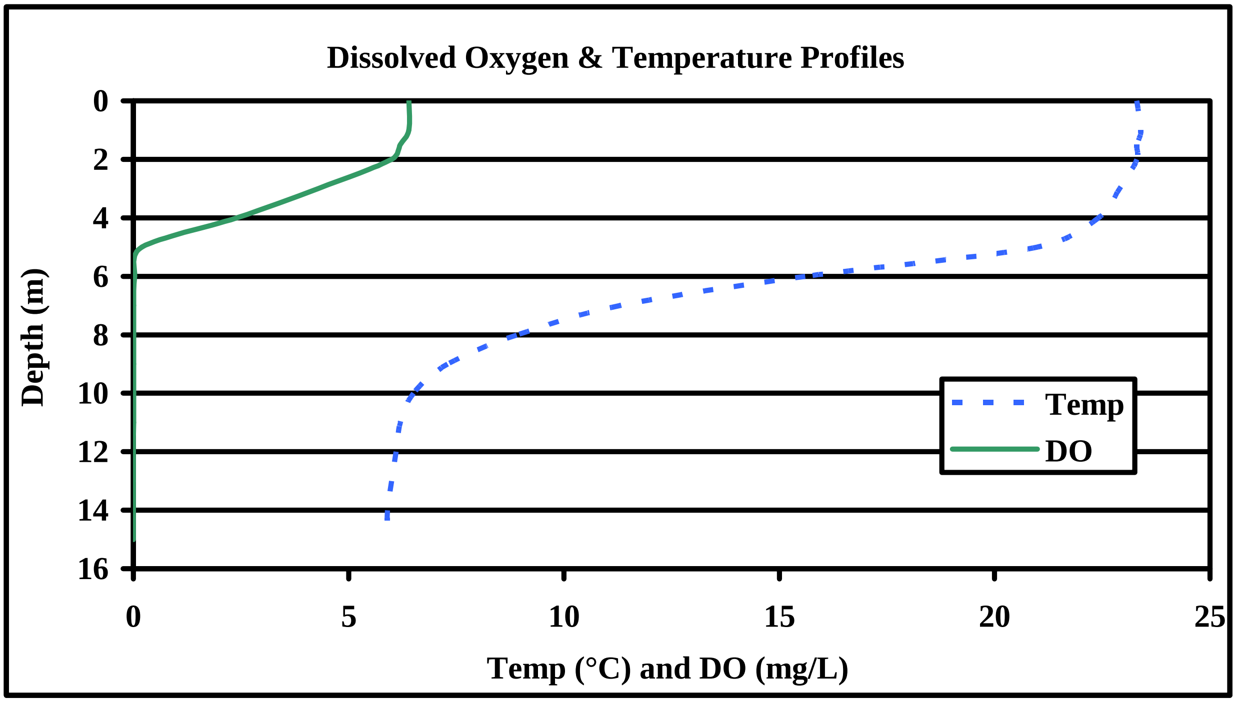

Figure 35. Temperature and dissolved oxygen profiles for Cook Lake on August 11, 2004.

Table 31. Water quality characteristics of Cook Lake, August 11, 2004.

Parameter	**Epilimnetic Sample**	**Hypolimnetic Sample**	**Indiana TSI Points (based on mean values)**
Conductivity	366 μmhos	267 μmhos	-
Secchi Depth Transparency	1.9 meters	-	0
Light Transmission @ 3 ft.	45%	-	3
1% Light Level	16 feet	-	-
Total Phosphorous	0.038 mg/L	0.413 mg/L	4
Soluble Reactive Phosphorous	0.010 mg/L*	0.316 mg/L	3
Nitrate-Nitrogen	0.013 mg/L*	0.013 mg/L*	0
Ammonia-Nitrogen	0.018 mg/L	2.614 mg/L	4
Organic Nitrogen	0.882 mg/L	0.949 mg/L	3
Oxygen Saturation @ 5ft.	73.1%	-	0
% Water Column Oxic	27%	-	4
Plankton Density	5,803 org/L	-	1
Blue-Green Dominance	72.6%	-	10
Chlorophyll *a*	8.2 μg/L	-	-

* Method Detection Limit **TSI Score** 36

The temperature profile for Cook Lake shows that the lake was stratified at the time of sampling (Figure 36). During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed *epilimnion* (surface waters) by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth, is called the *metalimnion*. At the time of sampling, the epilimnion was confined to the upper 13.1 feet (4 m) of water. The decline in temperature between 16.4 and 32.8 feet (5 and 10 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 10 meters.

The dissolved oxygen profile mirrors the temperature profile and is consistent with historical dissolved oxygen profiles for the lake (Figure 26). The oxygen concentration decreases rapidly within the epilimnion to a depth of 13.1 feet (5 m), at which there is no dissolved oxygen remaining in the lake. This is likely due to biological oxygen demand (BOD) from excess organic detritus in the lake's deeper waters. Respiration by aquatic fauna and decomposition of organic matter likely depleted the oxygen supply in the lake's deeper waters. Water below 13.1 feet (5 m) did not contain sufficient dissolved oxygen to support fish and other aquatic organisms. The lack of oxygen at the lake-sediment interface created conditions conducive to the release of phosphorus from the lake's sediments. Only 27% of the lake's water column was oxic, limiting the amount of habitat available for aquatic fauna.

Water clarity was relatively good in Cook Lake. The Secchi disk transparency depth was 6.2 feet (1.9 m) which is above the USEPA (2000b) target Secchi disk transparency depth of 4.6 feet (1.4 m). However, Cook Lake's transparency was below the median Secchi disk depth observed in Indiana lakes (6.9 feet or 2.1 m). Given its relatively good water clarity, it is not surprising that Cook Lake exhibited good light penetration through the water column. The lake's 1% light level, which limnologists use to determine the lower level where photosynthesis can occur, extended to 16 feet (4.9 m). Based on the depth-area curve in Figure 13, approximately 45% of the lake's surface area (approximately 43 acres) covers water shallower than 16 ft. This represents the area of the lake bottom with sufficient light to support rooted plant and algae growth. This area is called the ***littoral zone***. Based on the depth-volume curve (Figure 14), approximately 950 acre-feet of Cook Lake (58% of total lake volume) lies above the 16-foot 1% light level. This volume, referred to as the ***photic zone***, represents the amount of water with sufficient light to support algae growth. These two zones, the littoral zone and the photic zone, provide insight into the potential for primary production (plant growth) in Cook Lake.

Phosphorus and nitrogen are the primary plant nutrients in lakes and therefore are measured in lake water quality analyses. In the summer, Indiana lakes typically possess lower nutrient concentrations in their epilimnia compared to nutrient concentrations present in their hypolimnia. Algae in the lake's epilimnion often utilize a large portion of the readily available nutrients for growth. When the algae die and settle to the bottom sediments, nutrients are relocated to the hypolimnion. Higher concentrations of phosphorus in the hypolimnion may also result from chemical processes occurring at the sediment-water interface.

Total and soluble reactive phosphorus concentrations were generally high in Cook Lake. The total phosphorus concentration in Cook Lake's epilimnion was moderate for Indiana lakes.

Despite this, the total phosphorus concentration of 0.038 mg/L still exceeds the 0.03 mg/L concentration threshold that is considered high enough to support eutrophic conditions (Wetzel, 2001). The total phosphorus concentration was considerably higher in the hypolimnion, 0.413 mg/L. Likewise, the mean total phosphorus concentration exceeded the USEPA target total phosphorus concentration of 0.038 mg/L (USEPA, 2000a). The soluble reactive phosphorus concentration in the epilimnion was below the detection limit. This is typical in lakes since SRP is readily consumed by algae in the lake's epilimnion. The SRP concentration in Cook Lake's hypolimnion was high. The data indicate that most of the total phosphorus concentration in the hypolimnion consists of soluble reactive phosphorus. This dominance of the dissolved form of phosphorus coupled with the lack of oxygen in the deep waters over the bottom sediments suggests that dissolved phosphorus is being released from the lake's bottom sediments. This is called ***internal phosphorus loading*** and can be a significant additional source of phosphorus in some lakes. (The extent of internal phosphorus loading will be examined using a model later in this report.) Comparing the 2004 results to historic assessments, phosphorus concentrations appear to have increased since 1999 are very similar to the results obtained in 1989 and 1995..

Nitrate nitrogen concentrations were low throughout the water column. Nitrate concentrations measured 0.013 mg/L in both the epilimnion and the hypolimnion. Nitrate concentrations were below the USEPA target concentration of 0.016 mg/L (USEPA, 2000a). Nitrate is reduced to ammonia when oxygen is low. Cook Lake's hypolimnion lacks oxygen, therefore any nitrate reaching the lake's lower waters is quickly converted to ammonia. Ammonia is also a by-product of bacterial decomposition. The decomposition of organic matter likely occurring in Cook Lake's hypolimnion contributes to the relatively high ammonia concentration observed in Cook Lake's hypolimnion (2.614 mg/L). Like the total phosphorus concentration, ammonia concentrations, particularly the hypolimnetic concentration, has changed little since 1995 suggesting that water quality is relatively similar to that observed ten years ago.

Plankton enumerated from the sample collected from Cook Lake are shown in Table 32. Overall plankton density was relatively low measuring 5,803 organisms/L. The lake's chlorophyll *a* concentration was 8.2 μg/L, which is below the median chlorophyll *a* concentration measured in most Indiana lakes. Cook Lake's chlorophyll *a* concentration is slightly below the target USEPA chlorophyll *a* concentration of 8.6 μg/L (USEPA, 2000a). However, Cook Lake's chlorophyll *a* concentration exceeds Vollenweider's median chlorophyll *a* concentration measured in mesotrophic lakes (4.7 μg/L; Vollenweider, 1975). *Aphanizomenon*, a blue-green algae, was the most dominant algae found in Cook Lake accounting for nearly half of the plankton density. This particular blue-green algae as well as other blue-green species accounted for 73% of the plankton community. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers.

Table 32. The plankton sample representing the species assemblage in Cook Lake on August 11, 2004.

Species	Abundance (org/L)	Percentage of Plankton Population
Blue-green Algae (Cyanophyta)		
Anabaena	393	6.8%
Aphanizomenon	3,306	57.0%
Aphanocapsa	147	2.5%
Coelosphaerium	82	1.4%
Lyngbya	70	1.2%
Microcystis	35	0.6%
Oscillatoria	158	2.7%
Spirulina	23	0.4%
Green Algae (Chlorophyta)		
Closterium	6	0.1%
Pediastrum	6	0.1%
Staurastrum	18	0.3%
Ulothrix	135	2.3%
Diatoms (Bacillariophyta)		
Asterionella	6	0.1%
Fragilaria	492	8.5%
Other		0.0%
Ceratium	258	4.4%
Chrysosphaerella	182	3.1%
Mallomonas	358	6.2%
Synura	12	0.2%
Zooplankton - Cladocera		
Bosmina	1	0.0%
Calanoid	4	0.1%
Cyclopoid	14	0.2%
Daphnia	5	0.1%
Nauplii	19	0.3%
Zooplankton - Rotifera		
Keratella	59	1.0%
Polyarthra	18	0.3%
Total Number of Plankton	**5,803**	**100%**

Cook Lake Outlet

The Cook Lake outlet was sampled in conjunction with in-lake sampling conducted on August 11, 2004. The outlet connects Cook Lake to Millpond Lake via a culvert under Queen Road. Water moves directly from the wetland fringe around Cook Lake into the culvert pipe under Queen Road then into the wetland fringe around Millpond Lake. The culvert is approximately 30 feet (9.1 m) in length from Cook Lake to Millpond Lake. Water samples collected from the culvert provide insight into the typical (base) summertime flow of nutrients and sediment from Cook Lake to Millpond Lake. Results from the chemical analysis are included in Table 33.

Table 33. Analytical results for samples collected from the Cook Lake outlet on August 11, 2004.

Parameter	Analytical Result
Flow	1.42 cfs
Temperature	21.7 °C
Dissolved Oxygen	6.32 mg/L
Dissolved Oxygen Saturation	72%
Conductivity	353.6 μmhos/cm
Total Suspended Solids	2 mg/L
Turbidity	1.5 NTU
Ammonia-nitrogen	0.074 mg/L
Nitrate-nitrogen	0.013 mg/L*
Total Kjeldahl Nitrogen	0.817 mg/L
Soluble Reactive Phosphorus	0.010 mg/L*
Total Phosphorus	0.051 mg/L

* Method Detection Limit

As expected, many of the physical and chemical attributes of the water flowing through the culvert were similar to the physical and chemical composition of Cook Lake's epilimnion (Table 31). Temperature, dissolved oxygen, nitrate nitrogen, soluble reactive phosphorus concentrations were nearly identical to Cook Lake's epilimnion. Total phosphorus and ammonia nitrogen concentrations were higher in the culvert while total Kjeldahl nitrogen concentrations were lower in the culvert compared to Cook Lake's epilimnion. These differences however were slight. Measurements of water clarity were also consistent with the water clarity observed in the lake. Total suspended solids concentration and turbidity were low in samples taken from the culvert (2 mg/L and 1.5 NTU, respectively). Collectively, the data suggest summertime inputs of pollutants from Cook Lake to Millpond Lake is relatively low.

3.4.2 Holem Lake

Results from the Holem Lake water characteristics assessment are included in Figure 36 and Tables 34 and 35.

The temperature and oxygen profiles for Holem Lake are similar to those observed during historic water quality and fisheries assessments (Figure 36). Holem Lake's epilimnion extended from the water's surface to about 9.8 feet (3 m) below the surface at the time of sampling. The lake's metalimnion occurred between 9.8 and 19.7 feet (3 and 6 m), while a weakly-defined hypolimnion occupied water deeper than 19.7 feet (6 m). The dissolved oxygen profile was similar in shape to the temperature profile and indicated that a larger portion of the water column possesses anoxic conditions than was historically observed (Figure 29). The dissolved oxygen concentration rapidly declined within the epilimnion to a depth of 13.1 feet (4 m), at which point there is no dissolved oxygen remaining in the lake. Respiration by aquatic fauna and decomposition of organic matter likely depleted the dissolved oxygen supply in the lake's deeper water. Water below 13.1 feet (4 m) had insufficient dissolved oxygen content to support fish and other aquatic organisms. The lack of oxygen at the lake-sediment interface created conditions conducive to the release of phosphorus from the lake's sediments. Only 38% of the lake's water column was oxic, limiting the amount of habitat available for aquatic fauna.

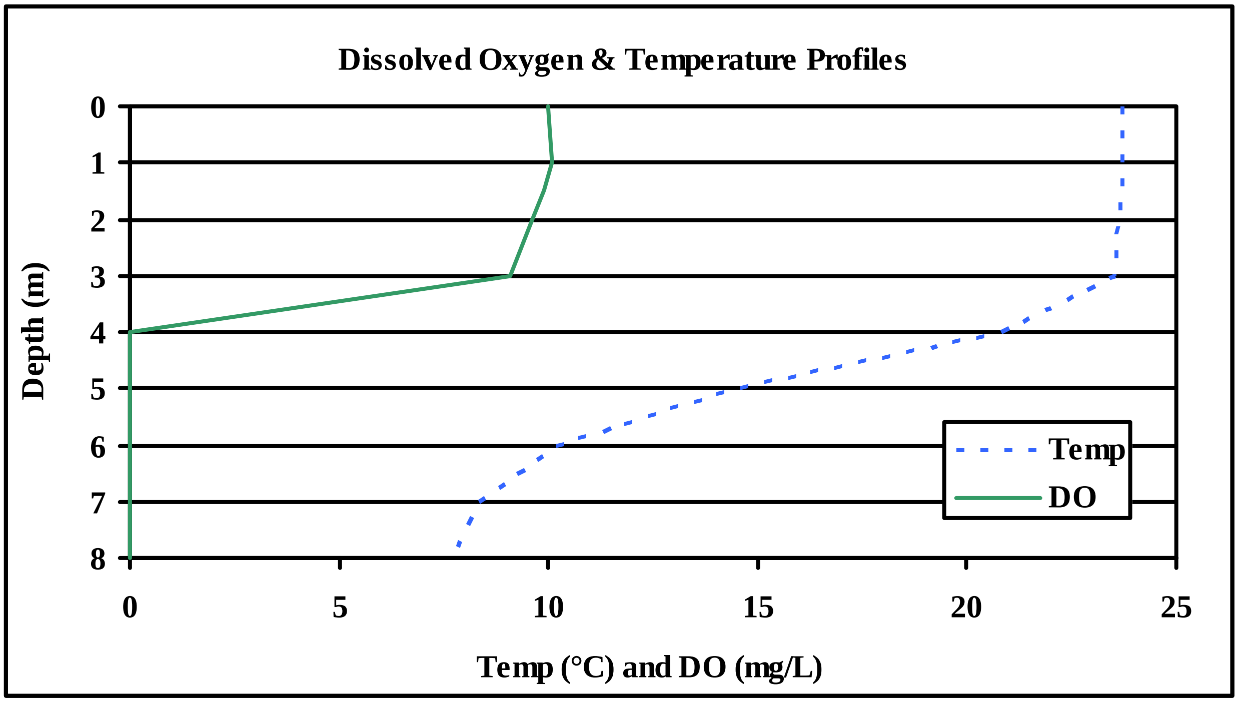

Figure 36. Temperature and dissolved oxygen profiles for Holem Lake on August 11, 2004.

Table 34. Water quality characteristics of Holem Lake, August 11, 2004.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
Conductivity	391 μmhos	324 μmhos	-
Secchi Depth Transparency	0.9 meters	-	6
Light Transmission @ 3 ft.	30%	-	4
1% Light Level	10 feet	-	-
Total Phosphorous	0.047 mg/L	0.199 mg/L	3
Soluble Reactive Phosphorous	0.010 mg/L*	0.152 mg/L	3
Nitrate-Nitrogen	0.013 mg/L*	0.013 mg/L*	0
Ammonia-Nitrogen	0.025 mg/L	1.534 mg/L	3
Organic Nitrogen	1.300 mg/L	1.215 mg/L	3
Oxygen Saturation @ 5ft.	117%	-	1
% Water Column Oxic	38%	-	3
Plankton Density	21,883 org/L	-	3
Blue-Green Dominance	93.1%	-	10
Chlorophyll *a*	27.68 μg/L	-	-
*Method Detection Limit		**TSI Score**	**39**

Water clarity was relatively poor in Holem Lake. The lake's Secchi disk depth was 2.9 feet (0.9 m), which is below the USEPA target Secchi disk transparency depth of 4.6 feet (1.4 m). Likewise, Holem Lake's transparency was below the median Secchi disk depth observed in Indiana lakes (6.9 feet or 2.1 m). Poor water clarity in Holem Lake limited the ability of light to penetrate through the water column. The lake's 1% light limit extended to only 10 feet (3.1 m).

Based on the depth-area and depth-volume curves displayed in Figures 16 and 17, this means that the lake's littoral zone covers almost 62% of the lake (approximately 24 acres) and the lake's photic zone occupies 218 acre-feet of Holem Lake (56% of total lake volume). In other words, although water clarity is poor, the shallow nature of Holem Lake results in nearly 60% of Holem Lake possessing enough light to support aquatic plant growth.

The lake was supersaturated with oxygen at 5 feet (1.5 m) and possessed a high chlorophyll *a* concentration. The percent dissolved oxygen at 5 feet (1.5 m) was 115% at the time of sampling. Supersaturation is usually symptomatic of intense phytoplankton photosynthesis. The high chlorophyll *a* concentration (27.68 μg/L) lends evidence to the hypothesis that the observed supersaturation was due to photosynthesizing algae. This concentration is nearly three times the target USEPA chlorophyll *a* concentration of 8.6 μg/L (USEPA, 2000a). Holem Lake's chlorophyll *a* concentration also exceeds Vollenweider's median chlorophyll *a* concentration measured in mesotrophic lakes (4.7 μg/L; Vollenweider, 1975). Light transmission at 3 feet (0.9 m) reflects the poor water clarity in the lake. Only 30% of incident light was measured at 3 feet (0.9 m) below the water's surface.

Several nutrients showed increases over historical concentrations, particularly in the hypolimnion. The lake's epilimnetic total phosphorus concentration is nearly double that observed during the 1995 and 1999 lake surveys. The hypolimnetic total phosphorus concentration decreased slightly from the concentrations observed historically. Much of the hypolimnetic total phosphorus concentration found during the current sampling effort is composed of soluble reactive phosphorus suggesting that the lake is releasing phosphorus from its bottom sediments. The lake's current hypolimnetic ammonia concentration is almost nearly double its 1999 concentration. Because ammonia is a by-product of decomposition, the elevated hypolimnetic ammonia concentration suggests that the lake is processing more organic matter than it did in 1999.

Table 35 presents plankton enumerated from the sample collected from Holem Lake. *Aphanizomenon*, a blue-green algae, was the most dominant genera found accounting for 86% of the plankton density. This particular blue-green algae along with other blue-green species accounted for 93% of the plankton community. Blue-greens are usually associated with degraded water quality. As noted in the *Cook Lake Section*, blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers.

Table 35. The plankton sample representing the species assemblage in Holem Lake on August 11, 2004.

Species	Abundance (org/L)	Percentage of Plankton Population
Blue-green (Cyanophyta)		
Anabaena	570	2.6%
Aphanizomenon	18,958	86.6%
Aphanocapsa	177	0.8%
Coelospharium	51	0.2%
Lyngbya	38	0.2%
Microcystis	355	1.6%
Oscillatoria	127	0.6%
Green (Chlorophyta)		
Staurastrum	38	0.2%
Ulothrix	51	0.2%
Diatoms (Bacillariophyta)		
Fragilaria	482	2.2%
Other		
Ceratium	558	2.5%
Chrysosphaerella	114	0.5%
Dinobryon	13	0.1%
Mallomonas	13	0.1%
Synura	51	0.2%
Zooplankton - Cladocera		
Bosmina	1	<0.1%
Calanoid	2	<0.1%
Ceriodaphnia	1	<0.1%
Cyclopoid	6	<0.1%
Daphnia	1	<0.1%
Nauplii	25	0.1%
Zooplankton - Rotifera		
Keratella	190	0.9%
Polyarthra	63	0.3%
Total Number of Plankton	**21,883**	**100%**

3.4.3 Kreighbaum Lake

Results from the Kreighbaum Lake water characteristics assessment are included in Figure 37 and Tables 36 and 37.

The temperature profile for Kreighbaum Lake shows that the lake was weakly stratified at the time of sampling (Figure 37). During complete thermal stratification, the hypolimnetic waters of the lake are completely isolated from the well-mixed epilimnetic waters by temperature induced density differences. At the time of sampling, Kreighbaum Lake's epilimnion consisted of the upper 3 feet (0.9 m) of water. Kreighbaum Lake did not possess a clearly defined hypolimnion or metalimnion. Rather, temperatures steadily declined with depth below 3 feet (0.9 m).

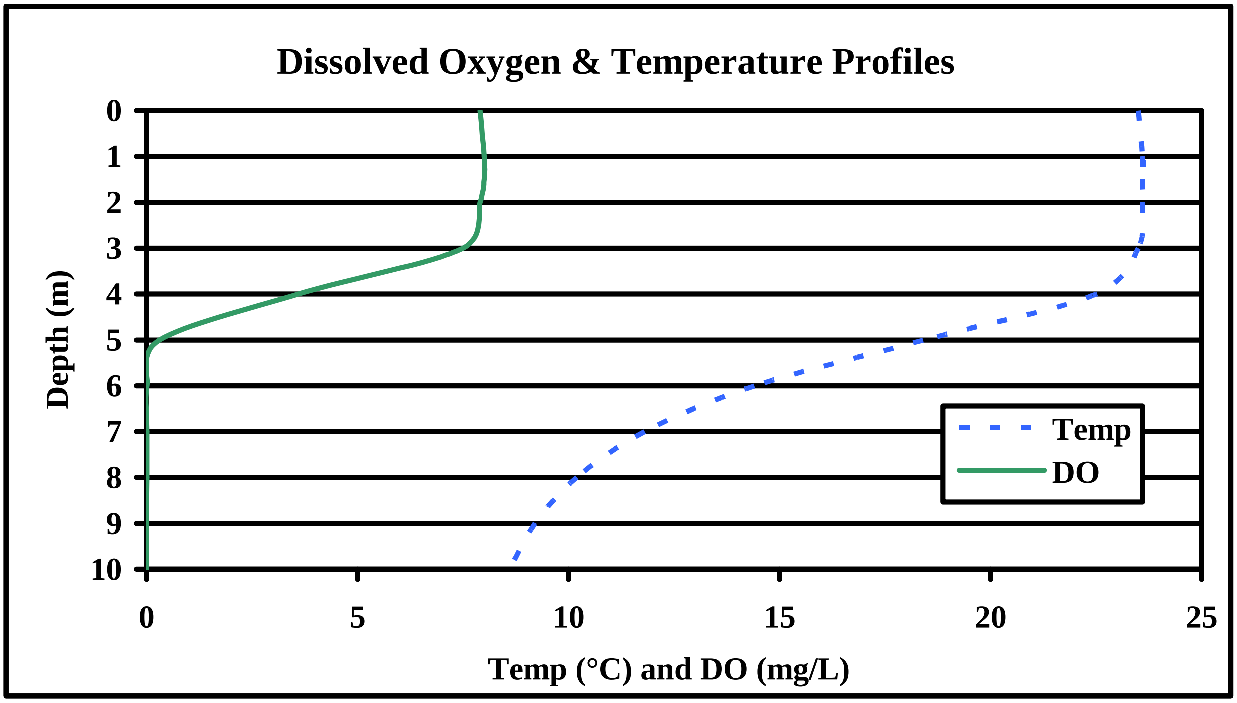

Figure 37. Temperature and dissolved oxygen profiles for Kreighbaum Lake on August 11, 2004.

Table 36. Water quality characteristics of Kreighbaum Lake, August 11, 2004.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
Conductivity	329 μmhos	324 μmhos	-
Secchi Depth Transparency	2.1 meters	-	0
Light Transmission @ 3 ft.	55%	-	2
1% Light Level	18 feet	-	-
Total Phosphorous	0.037 mg/L	0.382 mg/L	4
Soluble Reactive Phosphorous	0.010 mg/L*	0.301 mg/L	3
Nitrate-Nitrogen	0.013 mg/L*	0.013 mg/L*	0
Ammonia-Nitrogen	0.025 mg/L	2.493 mg/L	4
Organic Nitrogen	1.063 mg/L	1.645 mg/L	3
Oxygen Saturation @ 5ft.	90%	-	0
% Water Column Oxic	40%	-	3
Plankton Density	4,222 org/L	-	1
Blue-Green Dominance	84.3%	-	10
Chlorophyll *a*	5.21 μg/L	-	-
*Method Detection Limit		**TSI Score**	**30**

Kreighbaum Lake's dissolved oxygen profile is typical of productive lakes in Indiana. The lake's oxygen profile is generally consistent with the findings of previous studies on the lake. The upper 10 feet (3 m) of the lake were well oxygenated at the time of sampling. Kreighbaum Lake lacked oxygen below 16.4 feet (5 m), therefore only 40% of the lake was oxic. This limits the availability of habitat for fish and other aquatic organisms. This lack of dissolved oxygen at the sediment-water interface created conditions suitable for the release of phosphorus from the lake's sediment.

Water clarity was relatively good in Kreighbaum Lake. The lake's Secchi disk depth was 6.9 feet (2.1 m), which is better than the USEPA (2000b) target Secchi disk transparency depth of 4.6 feet (1.4 m). Kreighbaum Lake's transparency was equal to the median Secchi disk depth observed in Indiana lakes (6.9 feet or 2.1 m). Good water clarity in Kreighbaum Lake contributed to the ability of light to penetrate through the water column. The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 18 feet (5.5 m). Based on the depth-area curve in Figure 19, a 1% light level of 18 feet (5.5 m) means that the littoral zone occupies approximately 76% of the lake's surface area (approximately 30 acres). Additionally, based on the depth-volume curve (Figure 20), Kreighbaum Lake's photic zone encompasses approximately 355 acre-feet of Kreighbaum Lake (84% of total lake volume). In other words, the area where photosynthesis is possible represents a large portion of the total lake area and volume.

Nutrient concentrations measured in Kreighbaum Lake during the current survey are consistent with concentrations measured historically. At the time of sampling, the epilimnetic total phosphorus concentration was relatively low for Indiana lakes, but was still high enough to support nuisance algae blooms. As observed in the 1991, 1995, and 1999 lake evaluations, Kreighbaum Lake exhibited high or higher than hypolimnetic total and soluble reactive phosphorus concentrations. A large portion of the lake's hypolimnetic total phosphorus consisted of soluble reactive phosphorus, indicating that internal release of phosphorus from the lake's sediment is likely occurring. The lake's current hypolimnetic ammonia concentration is also generally consistent with concentrations measured historically. Because ammonia is a by-product of decomposition, the high hypolimnetic ammonia concentration suggests that the lake is processing high concentrations of organic matter.

Plankton enumerated from the sample collected from Kreighbaum Lake are shown in Table 37. Kreighbaum Lake's plankton density was relatively low (4,222 organisms/L). Kreighbaum Lake's chlorophyll *a* concentration was 5.21 μg/L, which is relatively moderate for Indiana lakes. Kreighbaum Lake's chlorophyll *a* concentration exceeds Vollenweider's median chlorophyll *a* concentration measured in mesotrophic lakes (4.7 μg/L; Vollenweider, 1975). However, Kreighbaum Lake's concentration is below the target USEPA chlorophyll *a* concentration of 8.59 μg/L (USEPA, 2000a). *Aphanizomenon* and *Oscillatoria*, both blue-green algal species, were the most dominant genera found. Each algal species accounted for 30 to 35% of the total plankton population. In total, blue-green species dominated the plankton community accounting for approximately 84%. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers.

Table 37. The plankton sample representing the species assemblage in Kreighbaum Lake on August 11, 2004.

Species	Abundance (org/L)	Percentage of Plankton Population
Blue-green (Cyanophyta)		
Anabaena	432	10.2%
Aphanizomenon	1490	35.3%
Aphanocapsa	12	0.3%
Coelospharium	35	0.8%
Lyngbya	12	0.3%
Microcystis	166	3.9%
Oscillatoria	1348	31.9%
Spirulina	65	1.5%
Green (Chlorophyta)		
Staurastrum	53	1.3%
Unknown (likely Limnothrix)	177	4.2%
Diatoms (Bacillariophyta)		
Fragilaria	278	6.6%
Unknown (Navicula?)	6	0.1%
Other		
Ceratium	183	4.3%
Chrysosphaerella	18	0.4%
Dinobryon	65	1.5%
Mallomonas	12	0.3%
Zooplankton - Cladocera		
Nauplii	14	0.3%
Calanoid	3	0.1%
Cyclopoid	4	0.1%
Daphnia	1	<0.1%
Ceriodaphnia	0.41	<0.1%
Bosmina	0.14	<0.1%
Zooplankton – Rotifera		
Keratella	53	1.3%
Trichocerca	6	0.1%
Polyarthra	12	0.3%
Total Plankton Population	**4,222**	**100%**

3.4.4 Millpond Lake

Results from the Millpond Lake water characteristics assessment are included in Figure 38 and Tables 38 and 39.

The temperature profile for Millpond Lake shows that the lake was very weakly stratified at the time of sampling (Figure 38). Temperatures steadily decreased with depth from the water surface to the lake bottom. This is likely due to the shallow nature of the lake. This year's temperature profile is very similar to the temperature profile observed in 1995 (Figure 34). Due to its shallow nature, wind mixing and boat turbulence likely prevent Millpond Lake from fully stratifying some years. While dissolved oxygen concentrations were high in the first 3 feet (0.9 m) of water, oxygen concentrations decline rapidly from the surface to a depth of 5 feet (1.5 m). At 5 feet (1.5

m) below the water's surface, the water was only 70% saturated with dissolved oxygen. The lake reached anoxic (DO < 1.0 mg/L) conditions around a depth of 5 feet (1.5 m). This is likely due to biochemical oxygen demand in the deeper waters. Water below 5 feet (1.5 m) did not contain sufficient oxygen content to support fish and other aquatic organisms.

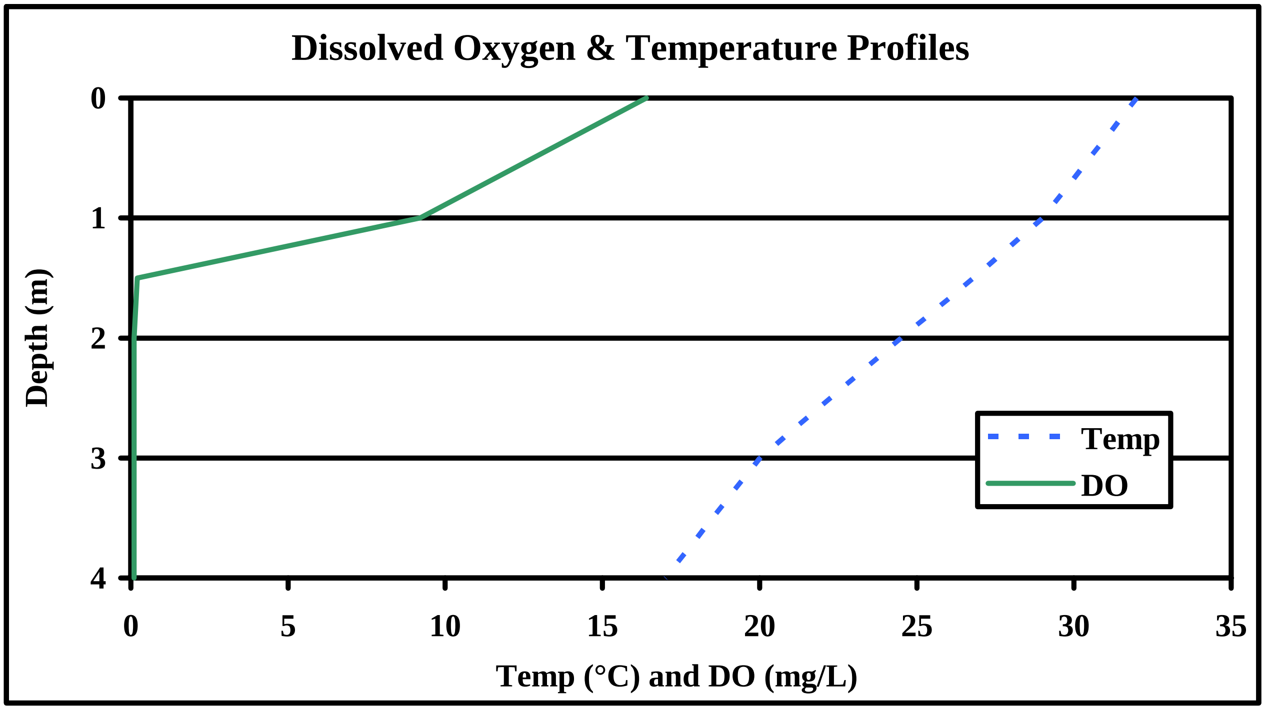

Figure 38. Temperature and dissolved oxygen profiles for Millpond Lake on August 11, 2004.

Table 38. Water quality characteristics of Millpond Lake, August 11, 2004.

Parameter	**Epilimnetic Sample**	**Hypolimnetic Sample**	**Indiana TSI Points (based on mean values)**
Conductivity	341 μmhos	340 μmhos	-
Secchi Depth Transparency	1.7 meters	-	0
Light Transmission @ 3 ft.	40 %	-	3
1% Light Level	10 feet	-	-
Total Phosphorous	0.061 mg/L	0.044 mg/L	2
Soluble Reactive Phosphorous	0.012 mg/L	0.013 mg/L	0
Nitrate-Nitrogen	0.013 mg/L*	0.013 mg/L*	0
Ammonia-Nitrogen	0.018 mg/L*	0.018 mg/L*	0
Organic Nitrogen	0.978 mg/L	0.872 mg/L	3
Oxygen Saturation @ 5ft.	70 %	-	0
% Water Column Oxic	75 %	-	1
Plankton Density	9,422 org/L	-	2
Blue-Green Dominance	68.4	-	10
Chlorophyll *a*	6.62 μg/L	-	-
		TSI Score	**21**

*Method Detection Limit

Water clarity in Millpond Lake was better than that observed in 1999. Millpond Lake exhibited a Secchi disk transparency depth of 5.6 feet (1.7 m). This Secchi disk depth is better than the target Secchi disk depth of approximately 4.6 feet (1.4 m) recommended by the USEPA (2000b). However, Millpond Lake's transparency was below the median Secchi disk depth observed in Indiana lakes (6.9 feet or 2.1 m). Light transmission was also good at the time of sampling, with approximately 40% of incident light reaching a depth of 3 feet (0.9 m) below the lake's surface. The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 10 ft (3.1 m). Based on the depth-area curve in Figure 22, approximately 94% of the lake is shallower than 10 ft (3.1 m). This represents the area of the lake bottom with sufficient light to support rooted plants or the littoral zone. Furthermore, based on the depth-volume curve (Figure 23), approximately 94% of volume of the lake lies above the 10-foot 1% light level. This volume represents the amount of water with sufficient light to support algae growth.

Nutrient concentrations within Millpond Lake are lower than those recorded during previous lake assessments. SRP and nitrate nitrogen concentrations were low measuring at or slightly above the laboratory detection limit in both the epilimnion and the hypolimnion. Ammonia concentrations were below the detection limit of 0.018 mg/L throughout the water column. Unlike the other lakes in the chain, Millpond Lake exhibited higher total phosphorus and organic nitrogen concentrations in the epilimnion than were present in the hypolimnion. Total phosphorus concentrations measured 0.061 mg/L in the surface waters and 0.044 mg/L near the bottom of the lake. Likewise, Millpond Lake possessed a higher epilimnetic organic nitrogen concentration (0.978 mg/L) compared to its hypolimnion (0.872 mg/L). The weak stratification present in Millpond Lake likely allows the lake to completely mix due to wind or wave action resulting in very similar nutrient concentrations throughout the water column.

Plankton enumerated from the sample collected from Millpond Lake are shown in Table 39. Millpond Lake possessed a plankton community of relatively low density (9,422 organisms/L). The lake's chlorophyll *a* concentration (6.62 μg/L) is relatively normal for Indiana lakes. This concentration is below the target USEPA chlorophyll *a* concentration of 8.59 μg/L (USEPA, 2000a). However, Millpond Lake's chlorophyll *a* concentration exceeds Vollenweider's median chlorophyll *a* concentration measured in mesotrophic lakes (4.7 μg/L; Vollenweider, 1975). Factors other than light may be limiting algae growth within the lake. Like the other lakes in the chain, Millpond Lake's plankton community was dominated by *Aphanizomenon*, which accounted for more than half of the plankton community at the time of the lake assessment. Nearly 70% of the overall plankton community consisted of blue-green algae. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers.

Table 39. The plankton sample representing the species assemblage in Millpond Lake on August 11, 2004.

Species	Abundance	Percentage of Plankton Population
Blue-green (Cyanophyta)		
Anabaena	421	4.5%
Aphanizomenon	5116	54.3%
Aphanocapsa	24	0.3%
Coelospharium	12	0.1%
Lyngbya	169	1.8%
Microcystis	349	3.7%
Oscillatoria	349	3.7%
Green (Chlorophyta)		
Pediastrum	12	0.1%
Staurastrum	96	1.0%
Unknown (likely Limnothrix)	108	1.1%
Diatoms (Bacillariophyta)		
Fragilaria	566	6.0%
Other		
Ceratium	578	6.1%
Chrysosphaerella	217	2.3%
Dinobryon	518	5.5%
Mallamonas	325	3.4%
Peridinium	24	0.3%
Synura	373	4.0%
Zooplankton - Cladocera		
Bosmina	4	<0.1%
Calanoid	7	0.1%
Cyclopoid	23	0.2%
Daphnia	18	0.2%
Nauplii	28	0.3%
Zooplankton - Rotifera		
Keratella	84	0.9%
Total Plankton Population	**9,422**	**100%**

3.4.5 Lake Assessment Summary and Discussion

The interpretation of a comprehensive set of water quality data can be quite complicated. Often attention is directed at the important plant nutrients (phosphorus and nitrogen) and to water transparency (Secchi disk depth) since dense algal blooms and poor transparency greatly affect the health and use of lakes.

To more fully understand the water quality data, it is useful to compare data from the lake in question to standards, if they exist, to other lakes, or to criteria that most limnologists agree upon. Because there are no nutrient standards for Indiana Lakes, results from Cook, Holem, Kreighbaum, and Millpond Lakes are compared below with data from other lakes and with generally accepted criteria.

Comparison with Vollenweider's Data

Results of studies conducted by Richard Vollenweider in the 1970's are often used as guidelines for evaluating concentrations of water quality parameters. His results are given in the Table 40. Vollenweider relates the concentrations of selected water quality parameters to a lake's ***trophic state***. The trophic state of a lake refers to its overall level of nutrition or biological productivity. Trophic categories include: ***oligotrophic***, ***mesotrophic***, ***eutrophic***, and ***hypereutrophic***. Lake conditions characteristic of these trophic states are:

Oligotrophic - lack of plant nutrients keep productivity low (i.e. few rooted plants, no algae blooms); lake contains oxygen at all depths; clear water; deeper lakes can support trout.

Mesotrophic - moderate plant productivity; hypolimnion may lack oxygen in summer; moderately clear water; warm water fisheries only - bass and perch may dominate.

Eutrophic - contains excess nutrients; blue-green algae dominate during summer; algae scums are probable at times; hypolimnion lacks oxygen in summer; poor transparency; rooted macrophyte problems may be evident.

Hypereutrophic - algal scums dominate in summer; few macrophytes; no oxygen in hypolimnion; fish kills possible in summer and under winter ice.

The units in the table are either milligrams per liter (mg/L) or micrograms per liter (µg/L). One mg/L is equivalent to one part per million (ppm) while one microgram per liter is equivalent to one part per billion (ppb). These are only guidelines; similar concentrations in a particular lake may not cause problems if something else is limiting the growth of algae or rooted plants.

Table 40. Mean values of some water quality parameters and their relationship to lake production (after Vollenweider, 1975).

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Total Phosphorus (mg/L)	0.008	0.027	0.084	>0.750
Total Nitrogen (mg/L)	0.661	0.753	1.875	-
Chlorophyll *a* (µg/L)	1.7	4.7	14.3	-

Table 41 shows the mean concentrations of total phosphorus, total nitrogen, and chlorophyll *a* for the Four Lakes. All of the lakes' mean total phosphorus concentrations exceed Vollenweider's mean total phosphorus concentrations in eutrophic lakes. Conversely, all of the lakes' mean total nitrogen concentrations exceed Vollenweider's mean total nitrogen concentration in mesotrophic lakes. Holem Lake's chlorophyll *a* concentrations were above the mean chlorophyll *a* concentration in Vollenweider's eutrophic lakes. Cook, Kreighbaum, and Millpond Lake's chlorophyll *a* concentration exceeded the mean chlorophyll *a* concentration in Vollenweider's mesotrophic lakes. This comparison indicates that the Four Lakes are moderately to very productive lakes.

Table 41. Comparison of mean total phosphorus, total nitrogen, and chlorophyll *a* results for the Four Lakes with Vollenweider's trophic classes.

Lake	Mean TP (mg/L)	Trophic Class	Mean TN (mg/L)	Trophic Class	Chl *a* (μg/L)	Trophic Class
Cook	0.225	eutrophic	0.915	mesotrophic	8.20	mesotrophic
Holem	0.123	eutrophic	1.258	mesotrophic	27.67	eutrophic
Kreighbaum	0.209	eutrophic	1.354	mesotrophic	5.21	mesotrophic
Millpond	0.053	eutrophic	0.925	mesotrophic	6.62	mesotrophic

Comparison with Other Indiana Lakes

The Cook, Holem, Kreighbaum, and Millpond Lakes results can also be compared with other Indiana lakes. Table 42 presents data from 456 Indiana lakes collected during July and August from 1994 to 2004 under the Indiana Clean Lakes Program. The set of data summarized in the table are mean values obtained by averaging the epilimnetic and hypolimnetic pollutant concentrations in samples from each of the 456 lakes. It should be noted that a wide variety of conditions, including geography, morphometry, time of year, and watershed characteristics, can influence the water quality of lakes. Thus, it is difficult to predict and even explain the reasons for the water quality of a given lake.

Table 42. Water quality characteristics of 456 Indiana lakes sampled from 1994 through 2004 by the Indiana Clean Lakes Program. Means of epilimnion and hypolimnion samples were used.

	Secchi Disk (ft)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	Chl *a* (μg/L)	Plankton (org/L)	Blue-Green Dominance (%)
Median	6.9	0.275	0.818	1.66	0.12	0.17	12.9	35,570	53.8
Maximum	32.8	9.4	22.5	27.05	2.84	2.81	380.4	753,170	100
Minimum	0.3	0.01	0.004	0.230	0.01	0.01	0.013	39	0.08

Table 43 compares the mean of selected water quality parameters for the Four Lakes to median value for all Indiana lakes. Most of the Four Lakes exhibited poorer transparency than most Indiana lakes. (Kreighbaum Lake possessed the same transparency as the Indiana median.) The lakes contained lower density plankton populations than those present in most Indiana Lakes. Likewise, all of the lakes, except Holem Lake, possessed lower chlorophyll *a* concentrations lower than those present in most Indiana lakes. Cook and Kreighbaum Lakes possessed higher total phosphorus concentrations and Holem Lake had a higher soluble reactive phosphorus concentration than most Indiana lakes. Kreighbaum Lake faired the best in its comparison. Kreighbaum Lake was better than the median of all sampled lakes in all parameters except total phosphorus concentration, blue-green algal dominance, and Secchi disk transparency. Kreighbaum Lake's Secchi disk transparency equaled the median Secchi disk transparency in Indiana lakes. Holem Lake faired the worst in this comparison. Five of its water quality parameters, including Secchi disk transparency, ammonia concentration, soluble reactive phosphorus concentration, chlorophyll *a* concentration, and blue-green algal dominance were worse than the median values for those parameters in Indiana lakes.

Table 43. Comparison of Cook, Holem, Kreighbaum, and Millpond Lakes to the median for all Indiana lakes for selected water parameters.

Lake	Secchi Disk	NO_3	NH_4	TKN	SRP	TP	Chl *a*	Plankton	Blue-Green Dominance
Cook	worse	better	better	better	better	worse	better	better	worse
Holem	worse	better	worse	better	worse	better	worse	better	worse
Kreighbaum	same	better	better	better	better	worse	better	better	worse
Millpond	worse	better	worse	better	better	better	better	better	worse

Using a Trophic State Index

In addition to simple comparisons with other lakes, lake water quality data can be evaluated through the use of a trophic state index or TSI. Indiana and many other states use a trophic state index (TSI) to help evaluate water quality data. A TSI condenses water quality data into a single, numeric index. Different index (or eutrophy) points are assigned for various water quality concentrations. The index total, or TSI, is the sum of individual eutrophy points for a lake.

The Indiana TSI

The Indiana TSI (ITSI) was developed by the Indiana State Pollution Control Board and published in 1986 (IDEM, 1986). The original ITSI differed slightly from the one in use today. Today's ITSI uses ten different water quality parameters to calculate a score. Table 44 shows the point values assigned to each parameter.

Table 44. The Indiana Trophic State Index.

Parameter and Range			Eutrophy Points
I.	Total Phosphorus (ppm)		
	A.	At least 0.03	1
	B.	0.04 to 0.05	2
	C.	0.06 to 0.19	3
	D.	0.2 to 0.99	4
	E.	1.0 or more	5
II.	Soluble Phosphorus (ppm)		
	A.	At least 0.03	1
	B.	0.04 to 0.05	2
	C.	0.06 to 0.19	3
	D.	0.2 to 0.99	4
	E.	1.0 or more	5
III.	Organic Nitrogen (ppm)		
	A.	At least 0.5	1
	B.	0.6 to 0.8	2
	C.	0.9 to 1.9	3
	D.	2.0 or more	4

IV.	Nitrate (ppm)		
	A.	At least 0.3	1
	B.	0.4 to 0.8	2
	C.	0.9 to 1.9	3
	D.	2.0 or more	4
V.	Ammonia (ppm)		
	A.	At least 0.3	1
	B.	0.4 to 0.5	2
	C.	0.6 to 0.9	3
	D.	1.0 or more	4
VI.	Dissolved Oxygen: Percent Saturation at 5 feet from surface		
	A.	114% or less	0
	B.	115% to 119%	1
	C.	120% to 129%	2
	D.	130% to 149%	3
	E.	150% or more	4
VII.	Dissolved Oxygen: Percent of measured water column with at least 0.1 ppm dissolved oxygen		
	A.	28% or less	4
	B.	29% to 49%	3
	C.	50% to 65%	2
	D.	66% to 75%	1
	E.	76% to 100%	0
VIII.	Light Penetration (Secchi Disk)		
	A.	Five feet or under	6
IX.	Light Transmission (Photocell) : Percent of light transmission at a depth of 3 feet		
	A.	0 to 30%	4
	B.	31% to 50%	3
	C.	51% to 70%	2
	D.	71% and up	0

X. Total Plankton per liter of water sampled from a single vertical tow between the 1% light level and the surface:

A.	Less than 3,000 organisms/L	0
B.	3,000 - 6,000 organisms/L	1
C.	6,001 - 16,000 organisms/L	2
D.	16,001 - 26,000 organisms/L	3
E.	26,001 - 36,000 organisms/L	4
F.	36,001 - 60,000 organisms/L	5
G.	60,001 - 95,000 organisms/L	10
H.	95,001 - 150,000 organisms/L	15
I.	150,001 - 5000,000 organisms/L	20
J.	Greater than 500,000 organisms/L	25
K.	Blue-Green Dominance: additional points	10

Values for each water quality parameter are totaled to obtain an ITSI score. Based on this score, lakes are then placed into one of five categories:

TSI Total	Water Quality Classification
0-15	Oligotrophic
16-31	Mesotrophic
32-46	Eutrophic
47-75	Hypereutrophic
*	Dystrophic

Four of these categories correspond to the qualitative lake productivity categories described earlier. The fifth category, dystrophic, is for lakes that possess high nutrient concentrations, but have limited rooted plant and algal productivity (IDEM, 2000). A rising TSI score for a particular lake from one year to the next indicates that water quality is worsening, while a lower TSI score indicates improved conditions. However, natural factors such as climate variation can cause changes in TSI scores that do not necessarily indicate a long-term change in lake condition. (Jones (1996) suggests that changes in TSI scores of 10 or more points are indicative of changes in trophic status, while smaller changes in TSI scores may be more attributable to natural fluctuations in water quality parameters.)

The Indiana Trophic State Index values calculated for Cook, Holem, Kreighbaum, and Millpond Lakes are shown in Table 45. The current sampling values place Kreighbaum and Millpond Lakes in the mesotrophic range, Cook Lake on the mesotrophic-eutrophic dividing line, and Holem Lake in the eutrophic range of the Indiana TSI. This conclusion is generally consistent with results obtained from the comparison of the lake data to Vollenweider's data (Table 40). The Vollenweider data indicate that Cook, Kreighbaum, and Millpond Lakes lie on the mesotrophic side of the mesotrophic-eutrophic dividing line, while Holem Lake falls on the eutrophic side of mesotrophic-eutrophic dividing line.

Table 45. The Four Lakes Indiana Trophic State Index scores for sampling conducted between the 1970s and 2004.

Lake	1970s	1989	1991	1995	1999	2004
Cook Lake	40	43	-	64	29	32
Holem Lake	23	41	-	30	23	39
Kreighbaum Lake	42	-	25	35	25	30
Millpond Lake	58	26	-	54	22	21

Because the ITSI captures one snapshot of a lake in time, using the Indiana TSI to track trends in lake productivity may be the best use of the Indiana TSI. Table 45 presents historical Indiana TSI scores for Cook, Holem, Kreighbaum, and Millpond Lakes. No clear trend is observable from Cook Lake's TSI scores. The TSI score in the 1970s is similar to the 1989 TSI score. The TSI score from the current study is similar to the 1999 TSI score. Comparing these two sets of TSI scores suggests a possible improvement in water quality. The 1995 TSI score is quite a bit higher than scores from any of the other assessments. The high TSI score from Cook Lake reflects the heavy reliance on algal parameters in the calculation of the ITSI. In 1995, Cook Lake received 35 points due to algae alone resulting in a rather high TSI score. The score may be more of a reflection of a one time event (an algal bloom) than the lake's true trophic state.

The historic ITSI scores do not elucidate any clear trends in water quality for the remaining three lakes in the chain. In Holem Lake, ITSI scores range from 23 to 41 with no evident trend. More recent assessment of Kreighbaum Lake show a fluctuation of only 10 points suggesting water quality has remained fairly stable in that lake over the past 13 years. Kreighbaum Lake's ITSI scores from 1991 to 2004 place the lake on the mesotrophic-eutrophic border line. This is consistent with the results from the comparison with Vollenweider's data. Millpond Lake's ITSI scores have fluctuated widely (27 points) over the past 30 years. As observed with Cook Lake, the high ITSI scores on Millpond Lake may be more reflecting of the ITSI's reliance on algal parameters than the lake's true condition. The lack of observable trend in the lakes' ITSI scores indicates that it is probably more useful to track individual components of the ITSI in each lake than the combined index. Isolation of trends in individual metrics would help clarify the lakes' water quality trend.

Using the ITSI to compare Cook, Holem, Kreighbaum, and Millpond Lakes to other lakes in the region, water quality is on par with or better than most lakes in the region. Based on data collected by the Indiana Clean Lakes Program's 1999 assessment, approximately 31% of the lakes in the Kankakee Basin (which includes the Four Lakes watershed) were classified as oligotrophic (IDEM, unpublished). Another 59% rated as mesotrophic, while 9% fell in the eutrophic category. Conversely, the 1995 Indiana Clean Lakes Program assessment rates 9% of lakes in the Kankakee Basin as oligotrophic, 48% as mesotrophic, 34% as eutrophic, and 9% as hypereutrophic (IDEM, unpublished). Kreighbaum and Millpond Lakes' placement in the mesotrophic category and Cook and Holem Lakes' placement in the eutrophic category based on the ITSI suggests that their water quality is on par or slightly lower than the water quality of lakes in the region.

The Carlson TSI

Because the Indiana TSI has not been statistically validated and because of its heavy reliance on algal parameters, the Carlson TSI may be more appropriate for evaluating Indiana lake data. Developed by Bob Carlson (1977), the Carlson TSI is the most widely used and accepted TSI. Carlson analyzed summertime total phosphorus, chlorophyll *a*, and Secchi disk transparency data for numerous lakes and found statistically significant relationships among the three parameters. He developed mathematical equations for these relationships, and these relationships form the basis for the Carlson TSI. Using this index, a TSI value can be generated by one of three measurements: Secchi disk transparency, chlorophyll *a*, or total phosphorus. Data for one parameter can also be used to predict a value for another. The TSI values range from 0 to 100. Each major TSI division (10, 20, 30, etc.) represents a doubling in algal biomass (Figure 39).

As a further aid in interpreting TSI results, Carlson's scale is divided into four lake productivity categories: oligotrophic (least productive), mesotrophic (moderately productive), eutrophic (very productive), and hypereutrophic (extremely productive).

Using Carlson's index, a lake with a summertime Secchi disk depth of 1 meter (3.3 feet) would have a TSI of 60 points (located in line with the 1 meter or 3.3 feet). This lake would be in the eutrophic category. Because the index was constructed using relationships among transparency, chlorophyll *a*, and total phosphorus, a lake having a Secchi disk depth of 1 meter (3.3 feet) would also be expected to have 20 µg/L chlorophyll *a* and 48 µg/L total phosphorus.

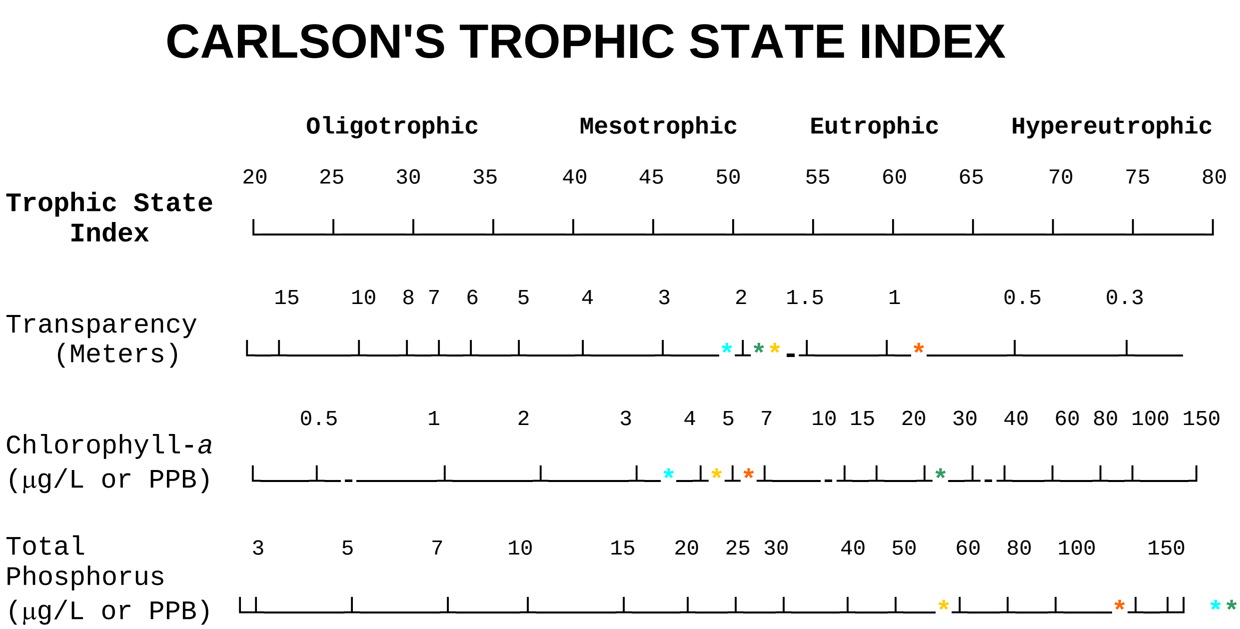

Figure 39. Carlson's Trophic State Index with Cook (*), Holem (*), Kreighbaum (*), and Millpond (*) Lakes results indicated by asterisks.

Not all lakes have the same relationship between transparency, chlorophyll *a*, and total phosphorus as Carlson's lakes do. Other factors such as high suspended sediments or heavy predation of algae by zooplankton may keep chlorophyll *a* concentrations lower than might be otherwise expected from the total phosphorus concentrations or transparency measurements. High suspended sediments would also make transparency worse than otherwise predicted by Carlson's index.

It is also useful to compare the actual trophic state points for a particular lake from one year to the next to detect any trends in changing water quality. While climate and other natural events will cause some variation in water quality over time (possibly 5-10 trophic points), larger point changes may indicate important changes in lake quality.

Analysis of Cook, Holem, Kreighbaum, and Millpond Lakes' transparencies and chlorophyll *a* concentrations according to Carlson's TSI suggests that the lakes are mesotrophic to eutrophic, while their total phosphorus concentrations indicate that the lakes are more hypereutrophic in nature (Figure 39; Table 46). Cook Lake's transparency places the lake in the mesotrophic to eutrophic category, while its chlorophyll *a* concentration places it in the eutrophic category. Cook Lake's total phosphorus concentration places it in the hypereutrophic category. Holem Lake's transparency and chlorophyll *a* concentration place the lake in the eutrophic category and its total phosphorus concentration places it in the hypereutrophic category. Kreighbaum Lake's chlorophyll *a* concentration place the lake in the mesotrophic category, while its transparency places in on the border between mesotrophic and eutrophic. Like Cook and Holem Lakes, Kreighbaum Lake's total phosphorus concentration places it in the hypereutrophic category. Millpond Lake's transparency and chlorophyll *a* concentration places the lake in the mesotrophic to eutrophic category, while its phosphorus concentrations place it in the eutrophic category. The four study lakes' high total phosphorus concentrations create conditions suitable for high levels of productivity. However, the relatively moderate transparency and moderate chlorophyll *a* concentrations present in the Cook, Kreighbaum, and Millpond Lakes indicate that they are not reaching their full productive potential. It is likely that something other than light penetration and phosphorus concentration is limiting algal production in these lakes. Conversely, Holem Lake's transparency and chlorophyll *a* concentration indicates that the lake's production more adequately reflects its phosphorus concentration than the other lakes in the chain.

Table 46. Comparison of Four Lake's trophic state scores and classifications using Carlson's Trophic State Index.

Lake	**Phosphorus**		**Secchi Disk**		**Chlorophyll *a***	
	TSI	**Classification**	**TSI**	**Classification**	**TSI**	**Classification**
Cook	82	hypereutrophic	51	mesotrophic-eutrophic	62	eutrophic
Holem	73	hypereutrophic	62	eutrophic	63	eutrophic
Kreighbaum	81	hypereutrophic	49	mesotrophic-eutrophic	46	mesotrophic
Millpond	61	eutrophic	52	mesotrophic-eutrophic	49	mesotrophic-eutrophic

Comparison of the Four Lakes Water Quality

Secchi disk transparency is a measure of suspended material in the water that interferes with light penetration. Resuspended bottom sediments, soil washed into the lake from watershed runoff, and algae all contribute to poor Secchi disk transparencies. Table 47 and Figure 40 demonstrate that the lakes with the lowest Secchi disk transparencies have the highest amounts of plankton and chlorophyll *a*. It is important to note that although Cook Lake has one of the best Secchi disk transparencies (6.2 feet or 1.9 m); it also has the highest rate of internal phosphorus release (31.9). If this internal phosphorus loading continues over time, the likelihood of dense algal growth in the lake will increase which, in turn, will greatly reduce this lake's transparency.

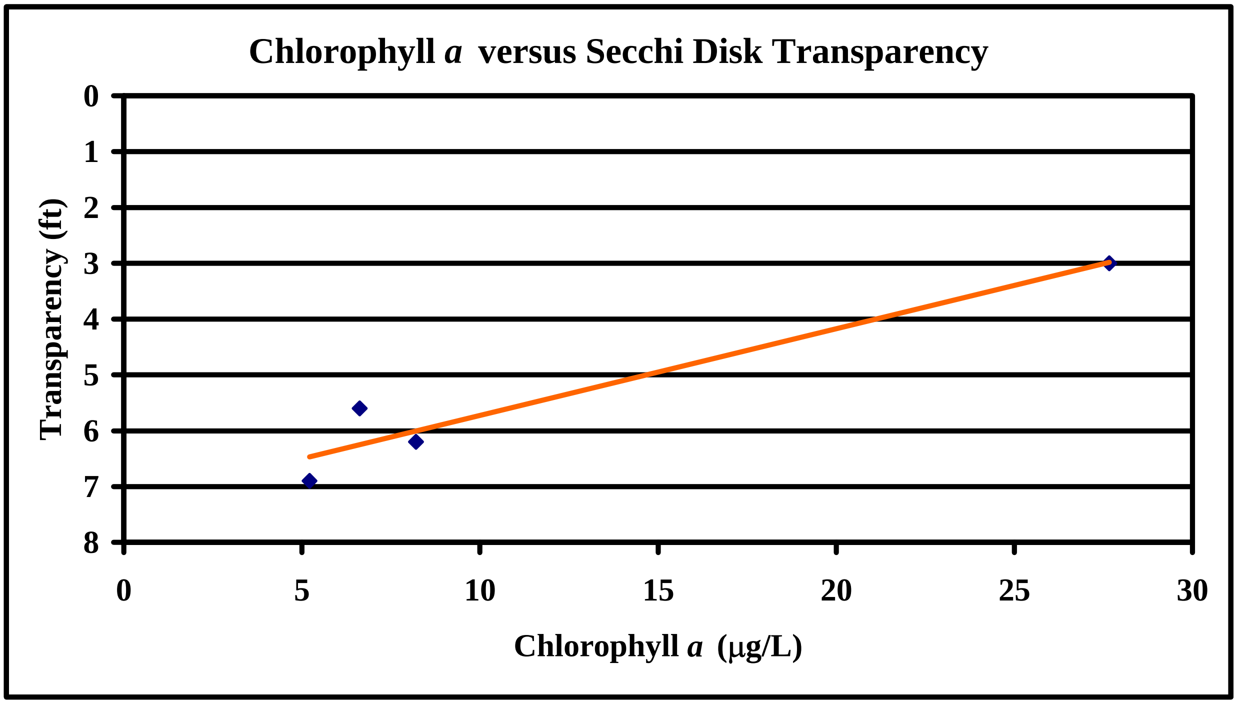

Figure 40. Relationship between Secchi disk transparency and chlorophyll *a* concentrations in Cook, Holem, Kreighbaum and Millpond Lakes. (R^2=0.956; $p<0.05$)

Table 47. Summary of water quality data for the Four Lakes, August 11, 2004.

Lake	Secchi Disk (ft)	Mean Total P (mg/L)	Mean SRP (mg/L)	Hypo NH_4 (mg/L)	TN:TP[1]	Sediment Phosphorus Release[2]	Chl. a (µg/L)	Total Plankton (org/L)
Cook	6.2	0.226	0.163	2.614	23.2	31.6	8.20	5,803
Holem	2.9	0.123	0.081	1.534	27.6	15.2	27.68	21,770
Kreighbaum	6.9	0.210	0.116	2.493	28.7	30.1	5.21	4,222
Millpond	5.6	0.053	0.013	0.872	16.0	1.1	6.62	9,422

[1]TN:TP ratios are calculated based on epilimnetic concentrations.
[2]Hypolimnetic Soluble Reactive Phosphorus (SRP) concentration/Epilimnetic SRP concentration. For example, Cook's hypolimnetic SRP concentration is 31.6 times that in the epilimnion. This difference is strong evidence of substantial internal loading of phosphorus.

In most lakes throughout Indiana, higher chlorophyll *a* concentrations are typically observed in lakes with higher total phosphorus concentrations (Jones, 1996). At the time of the current water quality sampling, the Four Lakes possessed a weakly defined, non-statistically significant relationship between epilimnetic total phosphorus and chlorophyll *a* concentrations (Figure 41). Holem and Kreighbaum Lakes provide the best examples of this relationship. Holem Lake contained the highest chlorophyll *a* concentration and possessed the second highest epilimnetic total phosphorus concentration. Kreighbaum Lake possessed the lowest epilimnetic total phosphorous concentration and contained the lowest chlorophyll *a* concentration. Conversely, Cook and Millpond Lakes do not follow the same pattern. Millpond Lake had the highest epilimnetic total phosphorus concentration but the second lowest chlorophyll *a* concentration, while Cook Lake contained the second highest chlorophyll *a* concentration, but possessed the second lowest epilimnetic total phosphorus concentration.

There are a variety of reasons why the correlation observed in Figure 41 is not as strong as expected. One possibility is that phosphorus is not the limiting nutrient. Typically, lakes with a total phosphorus ratio of greater than 7:1 is indicative of phosphorus limitation, while lakes with a total nitrogen to total phosphorus ratio of less than 7:1 are considered to be nitrogen limited (Gibson et al., 2000). Table 47 shows the Four Lakes' TN:TP ratios are all greater than 7:1 so nitrogen limitation is unlikely to be the cause for the weak correlation between chlorophyll a and epilimnetic total phosphorus. Another possibility is a high rate of zooplankton grazing is responsible for holding algae populations in check. A third possibility is that the epilimnetic phosphorus is in a form that is unusable (i.e. indigestible) by algae. The limited scope of this LARE study did not allow for eth sampling necessary to evaluate the latter two alternatives.

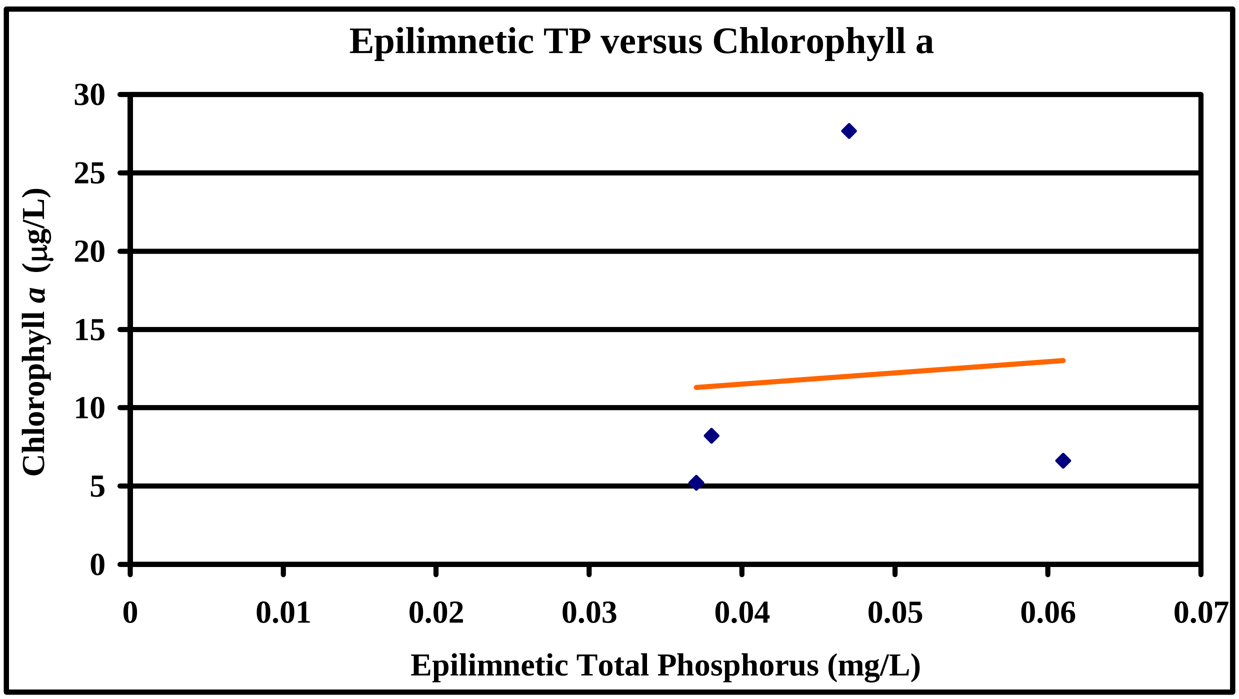

Figure 41. Non-statistically significant relationship between total phosphorus and chlorophyll *a* in Cook, Holem, Kreighbaum, and Millpond Lakes. (R^2=0.0056; p<0.05)

A final plausible reason for the lack of correlation between chlorophyll *a* and epilimnetic total phosphorus concentrations in the Four Lakes is the extensive rooted plant community support by these lakes. Experimental work has shown that rooted aquatic plants may help improve water clarity by promoting conditions that discourage the growth of algae and reduce non-algal turbidity (Moss, 1998; Scheffer et al., 2001). The reduction of algal biomass by rooted plants involves a suite of mechanisms, including: reducing nutrient concentrations in the water column; providing refuge for algae grazers to protect them from fish predators; preventing resuspension of sediment-attached nutrients; shading the water, thus limiting light available to algae; and producing algae growth inhibitors. The sum of these mechanisms produces a clear state within shallow lakes that appears to be self-stabilizing alternative to the turbid condition in which some shallow lakes exist. It is important to note that once nutrient concentrations reach a critical threshold, plant-dominated clear, shallow lakes can abruptly switch to turbid, algae-dominated lakes.

Summary

Cook, Holem, Kreighbaum, and Millpond Lakes all contain more phosphorus than is ideal. The potential exists for excessive algal production to occur in these lakes. (Evidence indicates that excessive algal production occurred in Cook and Millpond Lakes during the Clean Lakes Program 1995 assessments (Tables 17 and 29).) Cook, Holem, and Kreighbaum Lakes are considered hypereutrophic and Millpond Lake is considered eutrophic when evaluated with Carlson's total phosphorus TSI. While conditions visible on the surface of the Four Lakes may not appear overly bad, conditions in the lakes' hypolimnia are of concern. Years of excessive plant and algae production have led to the build-up of decaying organic matter in the sediments of Cook, Holem, and Kreighbaum Lakes. As bacteria decompose this material, they consume oxygen and leave the bottom waters anoxic. All of the lakes suffer from periods of anoxia.

Additionally, there is evidence of internal phosphorus release in some lakes (Table 47). There is considerably more soluble phosphorus in the hypolimnia (bottom waters) of Cook, Holem, and Kreighbaum Lakes when compared to the lakes' epilimnetic concentrations. This is strong evidence that phosphorus is being liberated from the sediments when oxygen is depleted or the lake is *anoxic* (dissolved oxygen concentrations < 1.0 mg/L). The column headed "Sediment Phosphorus Release" provides a comparison of the amount of soluble phosphorus (the form of phosphorus that can be released from the sediments) in the deepwater (hypolimnetic) samples to the surface (epilimnetic) samples. In Millpond Lake, the ratio is 1.1, which is quite low when compared to the sediment phosphorus release values calculated for the other three lakes. This suggests one of two things: that very little phosphorus release was occurring in Millpond Lake at the time of our sampling or that internal circulation within Millpond Lake was keeping the phosphorus concentration similar throughout the water column. In the other lakes, however, the ratio is greater than 1. This indicates that sediment phosphorus release is occurring. Cook and Kreighbaum Lakes have the highest phosphorus release rates. Phosphorus release from the sediments is an additional and important source of phosphorus to lakes that must be addressed along with watershed practices when designing a management plan to reduce nutrient loading to lakes. This *internal loading* of phosphorus is another source of phosphorus to these lakes that can promote excessive algae production.

Cook, Holem, and Kreighbaum Lakes also contain relatively high ammonia nitrogen concentrations in their hypolimnetic waters (Table 47). Ammonia is a by-product of bacterial decomposition. When ammonia occurs in high concentrations, it is evidence of high biological oxygen demand. This biological oxygen demand comes from organic waste, such as dead algae and rooted plants, within the sediments, which provides further evidence of excess algae and rooted plant growth in these lakes.

4.0 MACROPHYTE INVENTORY

4.1 Macrophyte Inventory Introduction

There are many reasons to conduct an aquatic rooted plant survey as part of a complete assessment of a lake and its watershed. Like other biota in a lake ecosystem (e.g. fish, microscopic plants and animals, etc.), the composition and structure of the lake's rooted plant community often provide insight into the long term water quality of a lake. While sampling the lake water's chemistry (dissolved oxygen, nutrient concentrations, etc.) is important, water chemistry sampling offers a single snapshot of the lake's condition. Because rooted plants live for many years in a lake, the composition and structure of this community reflects the water quality of the lake over a longer term. For example, if one samples the water chemistry of a typically clear lake immediately following a major storm event, the results may suggest that the lake suffers from poor clarity. However, if one examines the same lake and finds that rooted plant species such as northern water milfoil, white-stem pondweed, and large-leaf pondweed, all of which prefer clear water, dominate the plant community, one is more likely to conclude that the lake is typically clear and its current state of turbidity is due to the storm rather than being its inherent nature.

The composition and structure of a lake's rooted plant community also help limnologists understand why the lake's fish community has a certain composition and structure. For example, lakes with dense stands of rooted submerged plants often have large, stunted bluegill populations. Dense rooted plant stands provide ample cover or protection for small prey fish such as bluegills from larger predators such as largemouth bass. With greater coverage, the prey fish may begin to overpopulate the lake since fewer are being eaten by the predators. As the prey fish overpopulate, their food resources are spread thinner. This, in turn, leads to stunting of the prey fish. Similarly, lakes with depauperate emergent plant communities may have difficulty supporting some top predators that require the emergent vegetation for spawning. In these and other ways, the lake's rooted plant community illuminates possible reasons for a lake's fish community composition and structure.

A lake's rooted plant community impacts the recreational uses of the lake. Swimmers and power boaters desire lakes that are relatively plant-free, at least in certain portions of the lake. In contrast, anglers prefer lakes with adequate rooted plant coverage, since those lakes offer the best fishing opportunity. Before lake users can develop a realistic management plan for a lake, they must understand the existing rooted plant community and how to manage this community. This understanding is necessary to achieve the recreational goals lake users may have for a given lake.

For the reasons outlined above, as well as several others, JFNew conducted a general macrophyte (rooted plant) survey on Cook, Holem, Kreighbaum, and Millpond Lakes as part of the overall lake and watershed diagnostic study. Before detailing the results of the macrophyte survey, it may be useful to outline the conditions under which lakes may support macrophyte growth. Additionally, an understanding of the roles that macrophytes play in a healthy, functioning lake ecosystem is necessary for lake users to best manage the lake's macrophyte community. The following paragraphs provide some of this information.

Conditions for Growth

Like terrestrial vegetation, aquatic vegetation has several habitat requirements that need to be satisfied in order for the plants to grow or thrive. Aquatic plants depend on sunlight as an energy source. The amount of sunlight available to plants decreases with depth of water as algae, sediment, and other suspended particles block light penetration. Consequently, most aquatic plants are limited to maximum water depths of approximately 10 to 15 feet (3-4.5 m), but some species, such as Eurasian water milfoil, have a greater tolerance for lower light levels and can grow in water deeper than 32 feet (10 m) (Aiken et al., 1979). Hydrostatic pressure rather than light often limits plant growth in deeper water depth (15 to 20 feet or 4.5 to 6 m).

Shallower lakes have a greater potential to support aquatic plant growth than deeper lakes. Millpond Lake is the shallowest of the Four Lakes. It is shallow enough to be completely covered with aquatic plants. However, aquatic vegetation covers approximately 94% of Millpond Lake, suggesting that light and depth limit plant growth in this lake. Holem and Kreighbaum Lakes have a larger portion of shallow areas compared to Cook Lake, indicating that these lakes have the potential to support a greater percentage of aquatic plants than Cook Lake. While rooted plants do not cover all of the shallow areas of Holem and Kreighbaum Lakes, they do support more extensive rooted plant communities than those present at Cook Lake.

Water clarity affects the ability of sunlight to reach plants, even those rooted in shallow water. Lakes with clearer water have an increased potential for plant growth. At the time of the plant survey, the Four Lakes exhibited poorer water clarity than the average Indiana lake (6.9 feet or 2.1 m). Cook (6.2 feet or 1.9 m), Holem (2.9 feet or 0.85 m), Kreighbaum (5.5 feet or 1.7 m), and Millpond (6.8 feet or 2.1 m) Lakes all exhibit Secchi disk transparency depths that are shallower than most Indiana lakes. (These measurements were consistent with the Secchi disk depths measured for each lake during the in-lake sampling portion of this study.) Although Secchi disk transparencies are poorer than most Indiana lakes, the shallow nature of these lakes suggests a great potential for rooted plant growth. As a general rule, rooted plant growth is limited to the portion of the lake where water depth is less than or equal to 2 to 3 times the lake's Secchi disk depth. This is an estimate of the 1% light level. The lakes' 1% light levels as measured during the in-lake assessment with a photocell are moderate measuring 16 feet (4.9 m) for Cook Lake, 10 feet (3.1 m) for Holem Lake, 18 feet (5.4 m) for Kreighbaum Lake, and 10 feet (3.1 m) for Millpond Lake. These values suggest that low levels of light reach moderate depths in these lakes. Secchi disk transparency data (Table 46) and depth-area curves (Figures 13, 16, 19, and 22) indicate that the littoral zones of Cook (54%), Holem (59%), Kreighbaum (76%), and Millpond (94%) Lakes cover large percentages of the lakes. Base on this data, light clearly limits plant growth in Holem and Millpond Lakes.

Holem Lake possessed the poorest water clarity observed at the Four Lakes. The Secchi disk depth measured during the plant survey was 2.8 feet (0.85 m), which is consistent with the Secchi disk depth measured during the in-lake sampling portion of the study (2.95 feet or 0.9 m). The poorer water clarity likely impairs aquatic plant growth in deeper portions of the lake. Aquatic plants also require a steady source of nutrients for survival. Aquatic macrophytes differ from microscopic algae (which are also plants) in their uptake of nutrients. Aquatic macrophytes can receive their nutrients from the sediments via their root systems as well as directly utilizing nutrients in the surrounding water column. Some competition with algae for nutrients in the water column does occur. The amount of nutrients taken from the water column varies for each macrophyte species. Because macrophytes can obtain their nutrients from the sediments, lakes which receive high watershed inputs of nutrients to the water column will not necessarily have aquatic macrophyte problems.

A lake's substrate and the forces acting on the substrate also affect a lake's ability to support aquatic vegetation. Lakes that have mucky, organic, nutrient-rich substrates have an increased potential for plant growth compared to lakes with gravelly, rocky substrates. Sandy substrates that contain sufficient organic material typically support healthy aquatic plant communities. Lakes that have significant wave action that disturb the bottom sediments have decreased ability to support plants. Disturbance of bottom sediment may decrease water clarity, limiting light penetration, or may affect the availability of nutrients for the macrophytes. Wave action may also create significant shearing forces prohibiting plant growth altogether.

Boating activity may affect macrophyte growth in conflicting ways. Rooted plant growth may be limited if boating activity regularly disturbs bottom sediments. Since boat speed is limted on the Four Lakes, it is not likely that sufficient turbulence is created by boating on these lakes to impair aquatic plant growth significantly. Alternatively, boating activity in rooted plant stands of species that can reproduce vegetatively, such as Eurasian water milfoil, may increase macrophyte density rather than decrease it. Boating activity may be increasing the size and density of the Eurasian water milfoil and coontail stands in Cook, Holem, Kreighbaum, and Millpond Lakes.

Ecosystem Roles

Aquatic plants are a beneficial and necessary part of healthy lakes. Plants stabilize shorelines holding bank soil with their roots. The vegetation also dissipates wave energy further protecting shorelines from erosion. Plants play a role in a lake's nutrient cycle by up-taking nutrients from the sediments. Like their terrestrial counterparts, aquatic macrophytes produce oxygen which is utilized by the lake's fauna. Plants also produce flowers and unique leaf patterns that are aesthetically attractive.

Emergent and submerged plants provide important habitat for fish, insects, reptiles, amphibians, waterfowl, shorebirds, and small mammals. Fish utilize aquatic vegetation for cover from predators and for spawning and rearing grounds. Different species depend upon different percent coverages of these plants for successful spawning, rearing, and protection for predators. For example, bluegill require an area to be approximately 15-30% covered with aquatic plants for successful survival, while northern pike achieve success in areas where rooted plants cover 80% or more of the area (Borman et al., 1997).

Aquatic vegetation also serves as substrate for aquatic insects, the primary diet of insectivorous fish. Waterfowl and shorebirds depend on aquatic vegetation for nesting and brooding areas. Numerous aquatic waterfowl were observed utilizing Cook, Holem, Kreighbaum, and Millpond Lakes as habitat during the macrophyte survey. Aquatic plants such as pondweed, coontail, duckweed, water milfoil, and arrowhead also provide a food source to waterfowl. Duckweed in particular has been noted for its high protein content and consequently has served as feed for livestock. Turtles and snakes utilize emergent vegetation as basking sites. Amphibians rely on the emergent vegetation zones as primary habitat.

4.2 Macrophyte Inventory Methods

JFNew surveyed Cook, Holem, Kreighbaum, and Millpond Lakes on August 6, 2004 according to the Indiana State Tier One sampling protocol (Shuler and Hoffmann, 2002). JFNew examined the entire littoral zone of each lake. As defined in the protocol, the lakes' littoral zones were estimated to be approximately three times each lake's Secchi disk depth. This estimate approximates the 1% light level, or the level at which light penetration into the water column is sufficient to support plant growth. (See the *Lake Assessment Section* for a full discussion of the 1% light level and the reading recorded during the in-lake sampling effort.) At the time of sampling, Cook Lake's Secchi disk depth was 6.2 feet (1.9 m); thus its 1% light level was estimated to be approximately 18.6 feet (5.7 m). Consequently, JFNew sampled that area of Cook Lake that is less than 18.6 feet (5.7 m) deep. Similarly, Holem, Kreighbaum, and Millpond Lakes' Secchi disk depths were 2.8 feet (0.8 m), 5.5 feet (1.7 m), and 6.8 feet (2.1 m), respectively. Their 1% light levels were estimated to be 8.4 feet (2.6 m), 16.5 feet (5.0 m), and 20.4 feet (6.2 m), respectively. JFNew sampled the area of Holem Lake less than 8.5 feet (2.6 m), of Kreighbaum Lake less than 16.5 feet (5.0 m), and the entirety of Millpond Lake, which is less than 20.4 feet (6.2 m).

A survey crew, consisting of two aquatic ecologists and one botanist, surveyed Cook and Holem Lakes in a counter clockwise pattern starting at the Camper's Roost boat launch. The entirety of Cook Lake was surveyed prior to surveying Holem Lake. Likewise, Millpond Lake was surveyed in a counter clockwise pattern starting from the Millpond Lake public boat launch, while Kreighbaum Lake was surveyed in a counter-clockwise pattern starting at the channel connecting Kreighbaum Lake to Millpond Lake. The survey crew drove their boat in a zig-zag pattern across the littoral zone of each lake while visually identifying plant species. The crew maintained a tight pattern to ensure the entire zone was observed. In areas of dense plant coverage, rake grabs were performed to ensure all species were being identified. Once the crew had visually surveyed an entire plant bed, the crew broadly estimated species abundance, canopy coverage by strata (emergent, rooted floating, non-rooted floating, and submergent), and bed size. The crew also noted the bed's bottom substrate type. The crew recorded all data on data sheets (Appendix D). After completing one bed, the crew continued surveying the littoral zone until all plant beds were identified and the appropriate data were recorded.

4.3 Macrophyte Inventory Results

4.3.1 Cook Lake

A band of aquatic plants rings the edge of Cook Lake. The density of aquatic plant growth and canopy coverage varied across Cook Lake's littoral zone. Both light and residential development limit the growth of aquatic plants around Cook Lake. The western portion of the lake possessed the densest plant growth. On the west end of Cook Lake emergent plants extended across shallow areas and merged with floating and submerged plants to cover the entire width of the lake. Likewise, floating and submerged plant species dominated much of the southern shoreline extending 250 to 350 feet (60.9 to 106.7 m) from the lake shore. In contrast, plant growth along the northern shoreline was sparser, likely due the extensive residential development along the northern shoreline. On average, the plant community extended approximately 100 to 150 feet (30.5 to 45.7 m) from the northern shoreline. This was generally consistent with the estimated extent of the littoral zone based upon Cook Lake's Secchi disk depth of 6.2 feet (1.9 m) measured at the time of the aquatic plant survey. However, residents along the northern shoreline have altered this portion of the plant community by removing the floating and emergent portions of the plant community. Figure 42 shows the approximate boundaries of the Cook Lake plant bed.

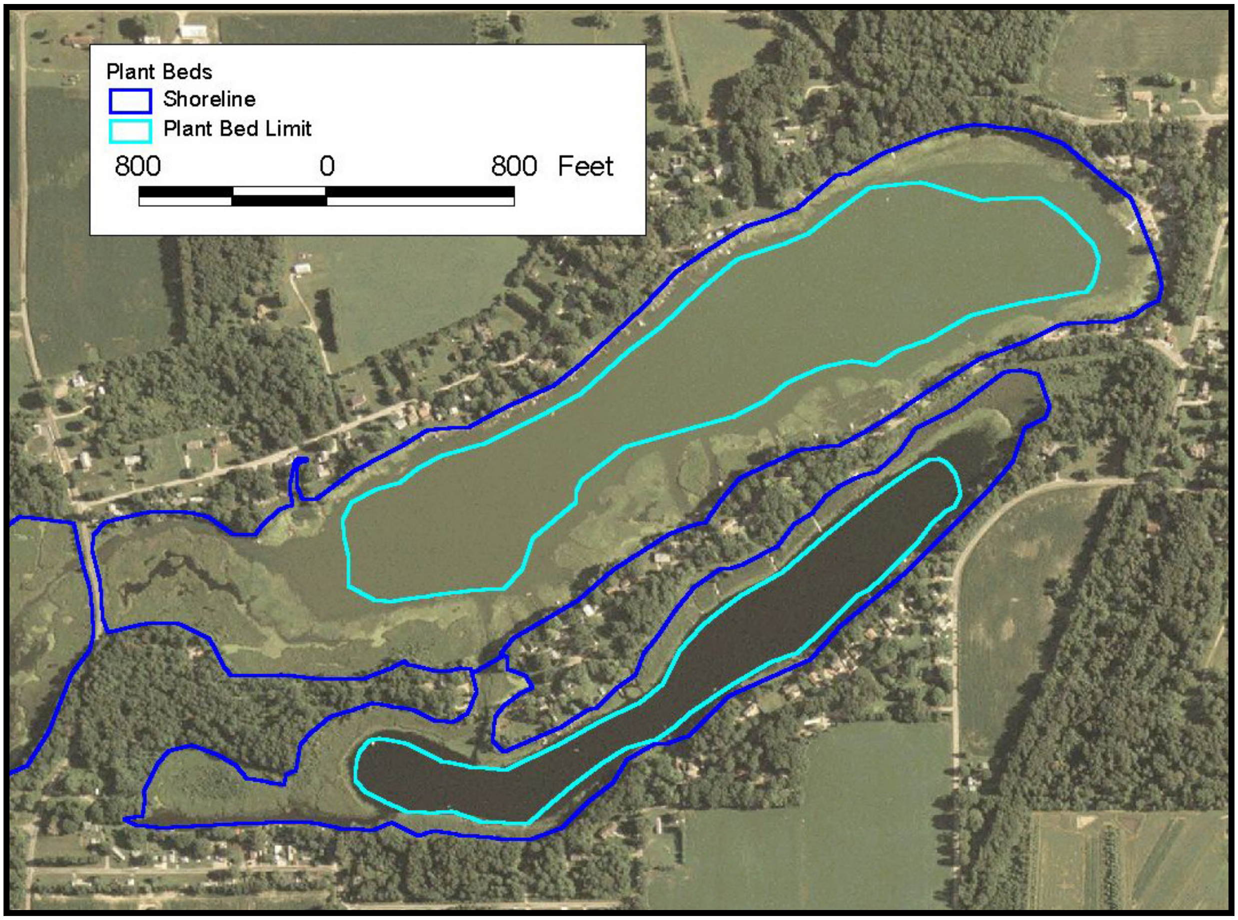

Figure 42. Cook and Holem Lake plant beds as mapped August 6, 2004.
Source: See Appendix A. Scale: 1"=800'

Cook Lake possesses the smallest littoral zone of any of the lakes in the chain. The Cook Lake plant survey revealed the presence of 36 plant species. The lake contained representative species from all three strata (emergent, submerged, and floating) of plant communities. Emergent plant species were the most diverse accounting for half of the total species by number. Whorled loosestrife, cattails, and purple loosestrife dominated the emergent plant community. These species possessed canopy abundance ratings of 2 to 20%. Other emergent species, including pickerel weed, arrowhead, silver maple, poison sumac, and smartweed, were also present in lower abundances. Submerged and rooted floating plants were co-dominant by abundance rating 21 to 60% canopy cover. Eurasian water milfoil and coontail dominated the submerged portion of the plant community. These species were located throughout the lake forming dense stands along much of the shoreline. Common waterweed, large-leaf pondweed, great bladderwort, and the exotic species, curly leaf pondweed, were present in lower numbers throughout the plant bed. Spatterdock, white water lily, and watermeal dominated the floating plant community. These species had canopy abundances of 2 to 60%. Filamentous algae coated many of the submerged plants throughout the Cook Lake.

4.3.2 Holem Lake

Like Cook Lake, a band of rooted plants rings Holem Lake. (This plant bed actually covers both Cook and Holem Lakes. JFNew created an arbitrary dividing line between Cook and Holem Lakes where the connecting channel attaches to Cook Lake. For the purpose of this discussion, and because the plant communities of Cook and Holem Lakes are structurally different, the plant communities of each lake are detailed separately.) A dense emergent and floating plant community covered both the east and west ends of Holem Lake and extended along the northern shoreline. On average, the plant community extended 100 to 150 feet (30.5 to 45.7 m) from the northern shoreline and approximately 75 to 80 feet (22.8 to 24.4 m) from the southern shoreline. These widths varied widely across the plant bed. Plants entirely covered the east and west ends of the lake with the plant bed extending across the entire width of Holem Lake. Poor water clarity prevented the identification of the maximum depth of plant establishment in Holem Lake; however, it is unlikely that the Holem Lake rooted plant community grew much beyond the approximate edge of the littoral zone (8.4 feet or 2.6 m) or aquatic plant average depth limits (approximately 12 feet or 3.8 m for most species). Figure 42 displays the approximate boundaries of the Holem Lake plant bed.

Holem Lake supports a structurally diverse plant community possessing emergent, floating, and submerged plants. Due to the lack of development along Holem Lake's shoreline, few manmade structures such as seawalls or beaches disturb the submerged, floating, and emergent plant communities. (The *Morphology and Shoreline Development Section* contains more detailed information about Holem Lake's shoreline.) Holem Lake's plant community was the most diverse of the Four Lakes supporting 50 species. Emergent species accounted for nearly 70% of the plant community by number including 36 of the 50 species identified within Holem Lake. Emergent plants covered 21 to 60% of the lake's plant bed. Purple loosestrife, cattails, whorled loosestrife, and a variety of willows dominated the emergent plant community. Purple loosestrife and cattails were co-dominant accounting for 21 to 60% of the emergent community canopy abundance, while whorled loosestrife and willows covered 2 to 20% of the plant bed. In addition to purple loosestrife, two other exotic species, common reed and reed canary grass, were present within the emergent plant community. Submerged species also covered 21 to 60% of the lake's plant bed. Coontail was pervasive throughout the plant bed. Dense stands of the species were present along much of the northern, eastern, and southern portions of the plant bed. Eurasian water milfoil was also a dominant component of the lake's submerged plant stratum. Other submerged species like great bladderwort, Illinois pondweed, large-leaf pondweed, and small pondweed existed in only small stands with few individuals. Rooted and non-rooted floating plants occupied 21 to 60% and 2 to 20% of the plant bed canopy, respectively. Spatterdock, white water lily, and watermeal dominated the floating plant stratum. Filamentous algae was also present throughout Holem Lake, covering many of the submerged species.

4.3.3 Kreighbaum Lake

Like Cook and Holm Lakes, rooted aquatic plants entirely ring Kreighbaum Lake forming one contiguous plant bed (Figure 43). (This plant bed actually covers both Millpond and Kreighbaum Lakes. JFNew created an arbitrary dividing line between Millpond and Kreighbaum Lakes where the connecting channel attaches to Millpond Lake. For the purpose of this discussion, and because the plant communities of Millpond and Kreighbaum Lakes are structurally different, the plant communities of each lake are detailed separately.) Kreighbaum Lake's aquatic plant community extended approximately 50 to 75 feet (15.2 to 22.9 m) from the northeastern, northern, and northwestern shorelines. Aquatic plants extended nearly 300 feet (91.4 m) from the shoreline of the upland island along the southern boundary of Kreighbaum Lake. Referring to the bathymetric map for Kreighbaum Lake, this data suggest that the plant community was restricted to depths near 15 feet (4.6 m). Occasionally, rooted plants were observed in deeper water (depths closer to 18 feet (5.5 m)). This is generally consistent with the estimated extent of the littoral zone based on the lake's Secchi disk depth of 5.5 feet (1.7 m) measured at the time of the plant survey. The lack of light in deeper waters near the center of the lake likely limit plant growth within this portion of Kreighbaum Lake.

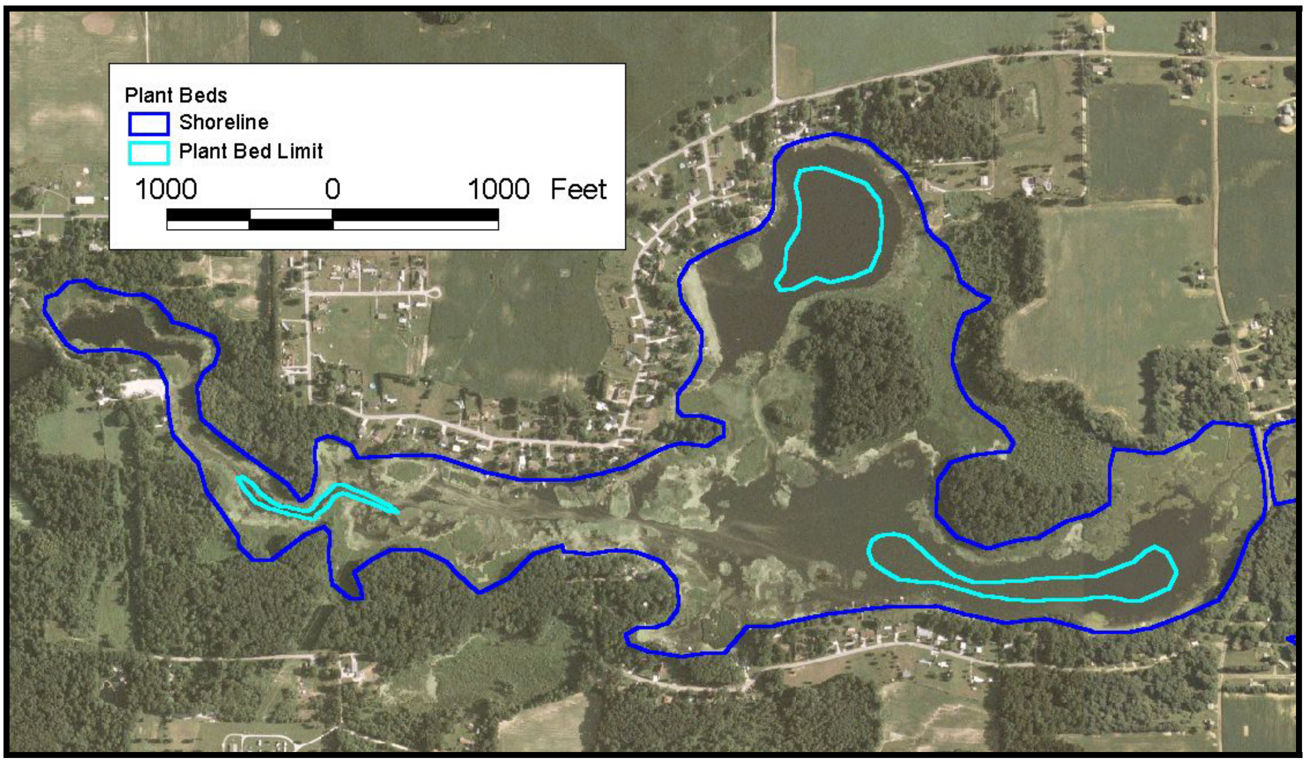

Figure 43. Kreighbaum and Millpond Lake plant beds as mapped August 6, 2004.
Source: See Appendix A. Scale: 1"=1,200'.

Kreighbaum Lake's littoral zone occupies a smaller percentage of the lake's surface area than Holem and Millpond Lakes. In total, 38 plant species cover approximately 68% of Kreighbaum Lake's surface area. These plants represent all three strata (emergent, floating, and submerged) of the plant communities. Submerged plants were the most diverse and dense group in the lake accounting for 16 of the 36 species by number and possessing a canopy abundance score of 21 to 60%. Coontail and Eurasian water milfoil dominated the plant community. These species possessed canopy abundance ratings of 21 to 60% and formed dense stands throughout much of the littoral zone. Curly leaf pondweed, chara, and Illinois pondweed also accounted for large portions of the submerged plant community. Floating vegetation including watermeal, white water lily, and spatterdock was also pervasive throughout the lake. Floating species covered 21 to 60% of Kreighbaum Lake's aquatic plant community. These plants were especially dense throughout the southern portion of the lake extending north along both the eastern and western shorelines. Emergent plants accounted for nearly half of the total plant diversity by number (14 of 36 species) but were less abundant than the floating and submerged strata. Emergent vegetation covered 2 to 20% of the aquatic plant bed. Cattails, pickerel weed, purple loosestrife, and whorled loosestrife dominated the emergent portion of the plant community. Purple loosestrife vegetated much of Kreighbaum Lake's shoreline and covered the shallow areas adjacent to the connecting channel to Millpond Lake and around the islands. Filamentous algae was also common throughout Kreighbaum Lake but was found in a much lower density than that observed in Millpond Lake.

4.3.4 Millpond Lake

Millpond Lake's natural history and extensive shallowness create favorable conditions for an extensive plant community. Rooted aquatic plants entirely ring Millpond Lake forming one contiguous plant bed covering approximately 94% of the lake's surface area. Submerged and floating plants were extremely thick in the bay northwest of the boat ramp, while emergent and floating plants covered much of the eastern end of the lake extending north and west around the islands. The lake's borders blend into the surrounding emergent and forested wetland around the island and in the northeast and southwest corners of Millpond Lake, blurring the dividing line between the lake and the surrounding wetlands. A mixture of submerged, emergent, and floating plants vegetated the embayments along the southern shoreline of Millpond Lake. Two small, isolated areas of the lake were devoid of aquatic plant growth. These areas are located in the deep hole near the east end of the lake and within the constricted channel between the boat ramp and the main body of the lake. Using the bathymetric map for Millpond, this suggests that the aquatic plant community was limited to water depths of less than 15 feet (4.6 m). This is generally consistent with the estimated extent of the littoral zone based on the lake's Secchi disk depth of 6.8 feet (2.1 m), measured at the time of the survey. Figure 43 shows the approximate location and extent of the Millpond plant bed.

The Millpond Lake plant survey revealed the presence of 38 species. The lake contained representative species from all three major strata (emergent, submerged, and floating) of plant communities. Emergent and submerged plant species were equally diverse with 15 species from each stratum. Whorled loosestrife, cattails, and purple loosestrife dominated the emergent portion of the plant community. These species possessed canopy abundance scores of 2 to 20% and were generally abundant along the entire shoreline. Coontail, great bladderwort, and Eurasian water milfoil were the major components of the submerged plant community. All three of these species had canopy abundance scores of 21 to 60%. Dense, nuisance stands of coontail, bladderwort, and Eurasian water milfoil covered nearly the entire lake. Other submerged species, such as common waterweed, creeping bladderwort, Illinois pondweed, and large-leaf pondweed were also common throughout the submerged plant community. Rooted and non-rooted floating plant species covered a large portion of the plant bed receiving canopy abundance scores of 21 to 60%. Spatterdock, white water lily, watermeal, and large duckweed were the dominant floating species. Filamentous algae also coated many of the rooted plants within Millpond Lake. Algae was especially thick in the cove northwest of the boat ramp.

4.4 Macrophyte Inventory Discussion

Generally, the aquatic plant community structure has changed little since early surveys of Cook, Holem, Kreighbaum, and Millpond Lakes. However, overall species richness and plant density appears to have increased in each of the lakes. Aerial photographs of the Four Lakes suggest that emergent plant cover increased over the past six years. (For comparison purposes, aerial photographs of Cook, Holem, Kreighbaum, and Millpond Lakes from 1998 and 2003 are contained in Appendix E). More specifics about each lake's plant community are listed below.

4.4.1 Cook Lake

In general, the results of the Cook Lake aquatic plant survey were consistent with findings from previous lake surveys. Historical studies recorded many of the same species that currently dominate Cook Lake. The 1970 and 1976 IDNR Division of Fish and Wildlife fisheries surveys of the lake rated spatterdock, water lily, swamp loosestrife, cattails, milfoil, bladderwort, coontail, and purple loosestrife as either common or abundant within the lake. (The 1970 and 1976 surveys conducted by the IDNR treat Cook and Holem Lakes as one body of water. Therefore plant species and associated abundances describe the communities present within both lakes at the time of the surveys.) The 2002 IDNR fisheries survey indicates that coontail and Eurasian water milfoil dominated the submerged plant community. Coontail was the most dominant species observed in 2002 with an average cover of 57% of all plant survey transects conducted within Cook Lake. Common duckweed and watermeal each covered approximately 50% of the three transects. Emergent and floating plants, including purple loosestrife, cattails, spatterdock, water lilies, watermeal, filamentous algae, and duckweed, covered 90% of Cook Lake's shoreline and approximately 5% of the lake's surface (Price and Robertson, 2003). The maximum depth at which plants were found was also similar among historical studies and the current study. During the current study, plants were not observed in water depths greater than 12 feet (3.6 m). The IDNR studies place the extent of the littoral zone closer to 8 feet (2.4 m) or 10 feet (3.0 m) as observed during the 1970 and 2002 surveys, respectively.

The biggest differences between the current study of Cook Lake's plant community and the historical studies are the variation in the diversity of submerged species and in the overall species richness. During the 1970 survey, the IDNR observed 25 plant species, 13 of which were submerged species. (The 1970 plant survey treated Cook and Holem Lakes as one lake; therefore, the plant list does not distinguish between plants observed in Cook or Holem Lakes.) The 2002 IDNR plant survey indicates that only 15 plant species, including 3 submerged species, were present within Cook Lake. The current survey reports the presence of 36 species (11 submerged) within Cook Lake. An increase in Secchi disk transparency from 3.75 feet (1.1 m) in 2002 to 6.2 feet (1.9 m) observed during the current study likely accounts for the increase in the number of submerged species. Additionally, a difference in survey methodology rather than an actual increase in the number of plant species in Cook Lake provides another explanation for the observed difference in species richness.

4.4.2 Holem Lake

In general, Holem Lake's plant community structure remains similar to communities observed historically. The 1970 IDNR fisheries survey of Cook and Holem Lakes lists spatterdock, water lily, swamp loosestrife, cattails, milfoil, bladderwort, and purple loosestrife as either common or abundant. The 2002 IDNR fisheries survey in Holem Lake noted the presence of coontail, Eurasian water milfoil, Illinois pondweed, variable pondweed, northern milfoil, chara, cattails, spatterdock, pickerel weed, and purple loosestrife. Watermeal, common duckweed, filamentous algae, and coontail had an average cover of 50 to 60% of the Holem Lake transect during the 2002 survey. Overall, cattails were the most prevalent aquatic plant species covering approximately 10% of Holem Lake. The maximum depth in which plants were found was similar among historical studies and the current study. During the current study, plants were not observed in water depths greater than 8 feet (2.4 m). The IDNR studies place the extent of the littoral zone close to 8 feet (2.4 m) in 1970 and 10 feet (3.0 m) in 2002.

The main difference between the current study of Holem Lake's plant community and historical studies is the increase in the diversity of emergent plant species and in overall species richness observed during the current study. The IDNR recorded the presence of 25 plant species during the 1970 fisheries survey. Purple loosestrife, swamp loosestrife, water willow, cattails, bulrush, and arrowhead were the only emergent plant species observed during that survey (Robertson, 1971). A total of 16 species were observed during the 2002 survey of Holem Lake. The IDNR recorded the presence of six emergent species including pickerel weed, arrowhead, cattails, purple loosestrife, and rushes. In contrast, 50 plant species were observed during the current survey; 34 of the 50 species were emergent species. Swamp rose, poison sumac, swamp milkweed, common boneset, water plantain, smartweed, reed canary grass, and common reed were just some of the emergent species observed during the current survey that were not previously observed at Holem Lake. Continued expansion of the emergent wetland into Holem Lake may account for some of the increase in emergent species observed in Holem Lake. A difference in survey methodology is likely another reason for the observed difference in emergent species diversity and overall species richness.

4.4.3 Kreighbaum Lake

The results of the current survey of Kreighbaum Lake are similar to results of the 1980 and 2003 surveys conducted on the lake. (The 1980 plant survey treated Kreighbaum and Millpond Lakes as one lake. The plant list included with the survey results does not distinguish between plants observed in Kreighbaum or Millpond Lakes.) Current survey results indicate that coontail, Eurasian water milfoil, chara, Illinois pondweed, purple loosestrife, cattails, pickerel weed, water willow, white water lily, spatterdock, and watermeal dominate Kreighbaum Lake's plant community. Historical studies record some of the same dominant species. The 1980 survey rated spatterdock, milfoil, curly leaf pondweed, and filamentous algae as common or heavy in the lake. IDNR fisheries biologists noted that plant cover was especially dense around the north shore of the islands separating Kreighbaum and Millpond Lakes. The July 2003 IDNR study completed in concert with the fishery survey noted the abundance of coontail in Kreighbaum Lake; coontail covered 65% of each of the transects surveyed during that study. The July 2003 survey also recorded the dominance of white water lily, watermeal, duckweed, and bladderwort and noted the presence of spatterdock, Eurasian water milfoil, and flat-stem pondweed in at least one of the transects. Results from the Tier II survey conducted by IDNR fisheries biologists in Kreighbaum Lake in August 2003 provide similar results. A total of 9 submerged species were identified during the survey. (The Tier II protocol is designed to assess the distribution and abundance of submerged plants; therefore, no emergent or floating plants were documented during the Tier II survey.) Filamentous algae and coontail were the most abundant species. These species were observed at 80% and 65% of the sample points, respectively. Coontail, great bladderwort, and filamentous algae accounted for 26%, 24%, and 16% of the aquatic plant community, respectively. During the Tier II survey, IDNR fisheries biologists indicated that on average aquatic plants covered 61 to 80% of Kreighbaum and Millpond Lakes.

The main difference between the current study of Kreighbaum Lake's plant community and the historically-recorded plant community is the species richness within the lake. The 1980 survey documented the presence of 8 species with many of the species rated as common and only one as abundant. The 2003 surveys noted the presence of 25 species within Kreighbaum and Millpond Lakes. (The fisheries report contains only one list for the two lakes.) During the current survey, 37 aquatic plant species were identified within the Kreighbaum Lake. Species previously identified throughout the lake, but recorded in low densities, including cattails, purple loosestrife, pickerel weed, and swamp loosestrife, were present throughout much of the lake during the current survey. As with Cook and Holem Lakes, the disparity in plant diversity is likely due to differences in survey methodology. Additionally, the presence of turbidity sensitive species, such as Illinois pondweed and large-leaf pondweed, likely indicates that water clarity has improved within Kreighbaum Lake over the past 25 years.

4.4.4. Millpond Lake

The results of the current survey of Millpond Lake are similar to results of the 1980 and 2003 surveys conducted on the lake. (As previously noted, the IDNR treated Kreighbaum and Millpond Lakes as one lake for the purpose of their fisheries surveys.) Current survey results indicate that coontail, milfoil, great bladderwort, spatterdock, and watermeal dominate Millpond Lake's plant community. Historical studies record many of the same dominant species. The 1980 survey described the abundance of spatterdock, milfoil, curly leaf pondweed, and filamentous algae as common or heavy. IDNR fisheries biologists noted that plant cover was especially dense in the west arm and at the east end of Millpond Lake and around the south side of the island separating Kreighbaum and Millpond Lakes. The July 2003 IDNR study noted the abundance of coontail in Millpond Lake which covered an average of 77% of the four transects surveyed within Millpond Lake. The July 2003 survey also recorded the dominance of spatterdock, white water lily, watermeal, duckweed, water willow, and purple loosestrife in each of the four transects and the presence of Eurasian water milfoil and common bladderwort within two of the transects. Results from the Tier II survey conducted by IDNR fisheries biologists in Millpond Lake in August 2003 provided similar results. A total of 10 submerged species were identified during the survey. (The Tier II protocol is designed to assess the distribution and abundance of submerged plants; therefore, no emergent or floating plants were documented during the Tier II survey.) Coontail and filamentous algae were the most abundant plant species in Millpond Lake. These species were observed at more than 95% of the sample points. Coontail accounted for 62% of the aquatic plant community, while filamentous algae, common bladderwort, and Eurasian water milfoil covered 19%, 12%, and 11.5%, respectively. During the Tier II survey, IDNR fisheries biologists indicated that on average aquatic plants covered 61 to 80% of Kreighbaum and Millpond Lakes.

The main difference between the current study of Millpond Lake's plant community and the historically-recorded plant community is the species richness within the lakes. The 1980 survey documented the presence of 8 species with many of the species rated as common and only one as abundant. The July and August 2003 surveys noted the presence of 25 species within

Kreighbaum and Millpond Lakes. During the current survey, 39 aquatic plant species were identified within Millpond Lake. Species previously identified throughout the lake, but recorded in low densities, including cattails, purple loosestrife, pickerel weed, and swamp loosestrife, were present throughout much of the lakes during the current survey. As with the other lakes in the chain, the disparity in plant diversity is likely due to differences in survey methodology.

4.4.5 Four Lakes Macrophyte Community Discussion

The plant communities of Cook, Holem, Kreighbaum, and Millpond Lakes reflect the water quality conditions in each of these lakes. Cook and Holem Lakes rate as eutrophic using Carlson's or the Indiana Trophic State Index, while Kreighbaum and Millpond Lakes rate as mesotrophic to eutrophic using Carlson's or the Indiana Trophic State Index. Each of the Four Lakes possesses a relatively high epilimnetic and mean total phosphorus concentration. Not surprisingly then, many of the dominant rooted plant species found in each lake are well adapted to eutrophic water quality conditions. For example, coontail, which is very tolerant of eutrophic conditions, is a dominant species in each of the lakes. Eurasian water milfoil, which is similarly tolerant of poor water quality, is a major component in each lakes' submerged community. Millpond Lake, which possessed the highest epilimnetic total phosphorus concentration of the Four Lakes, and Cook Lake, which possessed the highest mean total phosphorus concentration, also support dense populations of filamentous algae, watermeal, and duckweed. These species obtain their nutrients directly from the water column, so they are typically abundant in high nutrient lakes. Given the elevated nutrient levels in Cook, Holem, Kreighbaum, and Millpond Lakes, these species have a competitive edge over other species that cannot directly utilize nutrients from the water column.

While Cook, Holem, Kreighbaum, and Millpond Lakes' water quality likely helps shape their aquatic plant communities' composition and structure, the composition and structure of the plant communities likely play a role in shaping the lakes' fish communities. Historical fisheries surveys (Robertson, 1971; Robertson, 1977; Rowe, 1981; Price and Robertson, 2003; Price, 2004) indicated that bluegill dominate Cook, Holem, Kreighbaum, and Millpond Lakes' fish communities. This species accounts for more than 70% of Cook and Holem Lakes' fish community and approximately 50% of Kreighbaum and Millpond Lakes' fish community by number. The survey conducted in Kreighbaum and Millpond Lakes indicate that bluegill growth rates are lower in these lakes than growth rates observed in area lakes (Price, 2004). Likewise, Price (2004) indicates that largemouth and smallmouth bass population densities are below average for area lakes. Although, these issues are not yet problematic within the Four Lakes, the issues are symptomatic of lakes that support dense aquatic plant communities. Dense plant beds offer cover for bluegill and other forage species, protecting them from predators such as largemouth bass. As a result, the bluegill population grows unchecked. As the population grows, there are fewer food resources to support the population, resulting in slow growth rates and stunted individuals. Large beds of coontail and Eurasian water milfoil are a particular problem for establishing a balanced fishery. The structure of these species is such that individual plants growing side by side can form a tight network of leaflets and branches. This leaves little room for larger fish. In contrast, beds of species such as large-leaf pondweed possess a looser network of leaves and provide larger holes for fish. Four Lakes residents should continue to work with the IDNR fisheries biologist to manage plant densities for the production of healthy fish communities.

Nuisance and Exotic Plants

All four study lakes support several nuisance and/or exotic aquatic plant species. Figures 44 and 45 indicate the general location of these species within or adjacent to the lakes. As nuisance species, these species will continue to proliferate if unmanaged, so Figures 44 and 45 will be outdated quickly and should not be used to precisely locate nuisance species individuals or stands. (Additionally, it is likely that the watershed supports some terrestrial nuisance species plant species, but this discussion will focus on the aquatic nuisance species.) The plant surveys revealed the presence of Eurasian water milfoil, a submerged aggressive exotic, and purple loosestrife in or along all four study lakes. Cook, Kreighbaum, and Millpond Lakes support one additional submerged exotic species: curly leaf pondweed. (IDNR plant treatment permits indicate that curly leaf pondweed was previously observed in and treated for within Holem Lake; however, this species was not identified during the current survey.) Two emergent exotic species, common reed and reed canary grass, were observed along the southern shoreline of Holem Lake. As nuisance species, these species have the potential to proliferate if left unmanaged, so lake residents and visitors must treat these species as a threat to their lakes' health. It is possible that these or other exotic species could exist within the thick emergent portions of the rooted plant community but were not observed during this survey.

The presence of Eurasian water milfoil in the four study lakes is of concern, but it is not uncommon for lakes in the region. Eurasian water milfoil is an aggressive, non-native species. It often grows in dense mats excluding the establishment of other plants. For example, once the plant reaches the water's surface, it will continue growing horizontally across the water's surface. This growth pattern has the potential to shade other submerged species preventing their growth and establishment. In addition, Eurasian water milfoil does not provide the same habitat potential for aquatic fauna as many native pondweeds. Its leaflets serve as poor substrate for aquatic insect larva, the primary food source of many panfish.

Depending upon water chemistry, curly leaf pondweed can be less aggressive than Eurasian water milfoil. Despite this, its presence in Cook, Kreighbaum, and Millpond Lakes is still of concern. Like many exotics, curly leaf pondweed gains a competitive advantage over native submerged species by sprouting early in the year. The species can do this because it is very tolerant of cooler water temperatures compared to many of the native submerged species. Curly leaf pondweed experiences die back during early to mid summer. This die back can degrade water quality by releasing nutrients into the water column and increasing the biological oxygen demand. This is particularly harmful to Cook and Kreighbaum Lakes since these lakes already possess high nutrient levels and low levels of oxygen. (See the *Lake Assessment Section* for more details.)

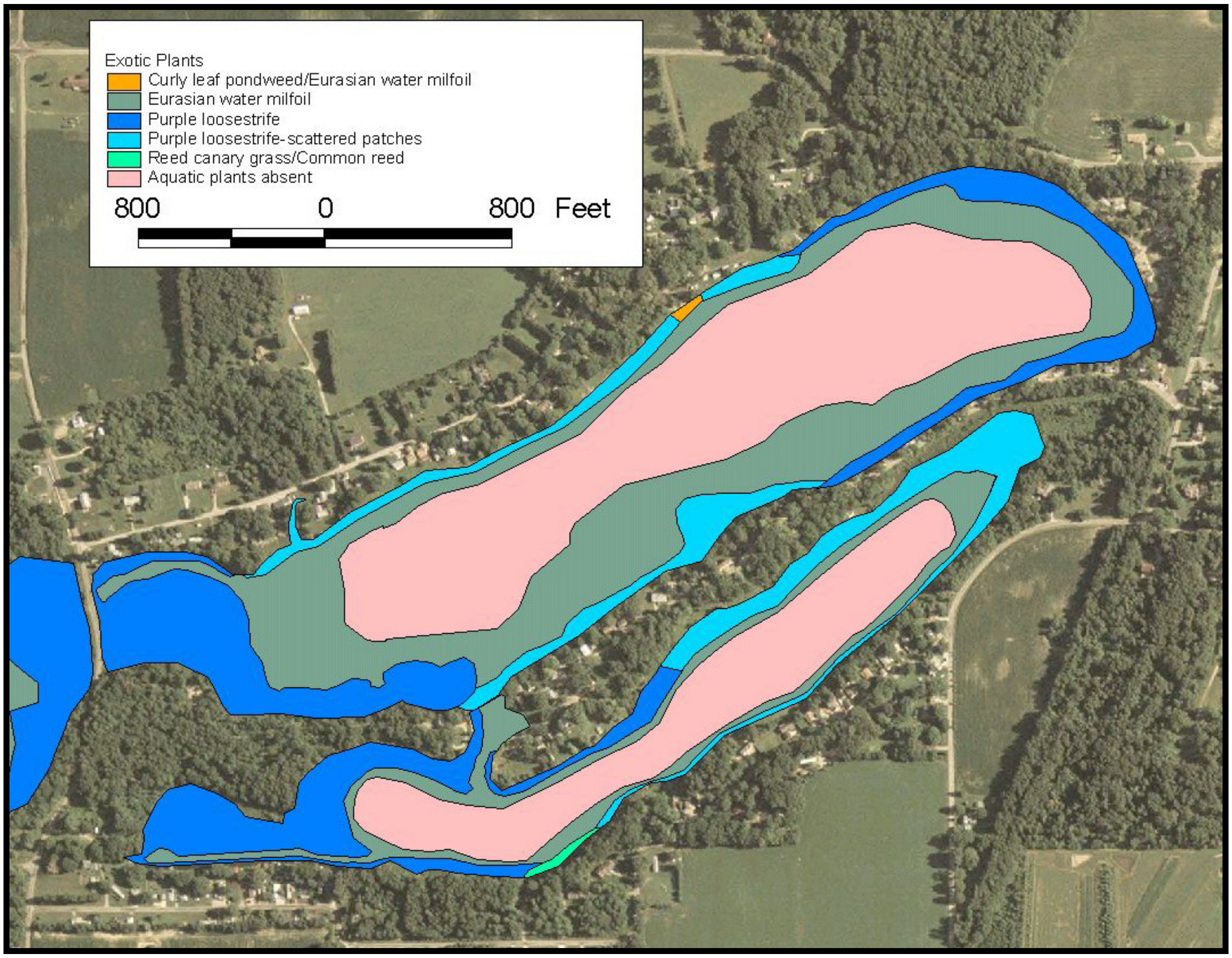

Figure 44. Exotic aquatic plant species locations within Cook and Holem Lakes as mapped August 6, 2004.
Source: See Appendix A. Scale: 1"=800'.

Purple loosestrife is an aggressive, exotic species introduced into this country from Eurasia for use as an ornamental garden plant. Like Eurasian water milfoil, purple loosestrife has the potential to dominate habitats, in this case wetland and shoreline communities, excluding native plants. The stiff, woody composition of purple loosestrife makes it a poor food source substitute for many of the native emergents it replaces. In addition, the loss of diversity that occurs as purple loosestrife takes over plant communities lowers the wetland and shoreline habitat quality for waterfowl, fishes, and aquatic insects. Purple loosestrife was observed in several locations along a majority of the Four Lakes' shoreline. In some areas, purple loosestrife coverage is dense.

Two other nuisance emergent species, reed canary grass and common reed, grow along Holem Lake's shoreline. Although their populations are small compared to the extent of purple loosestrife coverage, these species are still of concern. Like purple loosestrife, reed canary grass is native to Eurasia. Farmers used (and many likely still use) the species for erosion control along ditch banks or as marsh hay. The species escaped via ditches and has spread to many of the wetlands in the area. Swink and Wilhelm (1994) indicate that reed canary grass commonly occurs at the toe of the upland slope around a wetland. This is its exact location around Holem

Lake. Like other nuisance species, reed canary grass forms a monoculture mat excluding native wetland/shoreline plants. This limits a wetland's diversity ultimately impacting the wetland's functions.

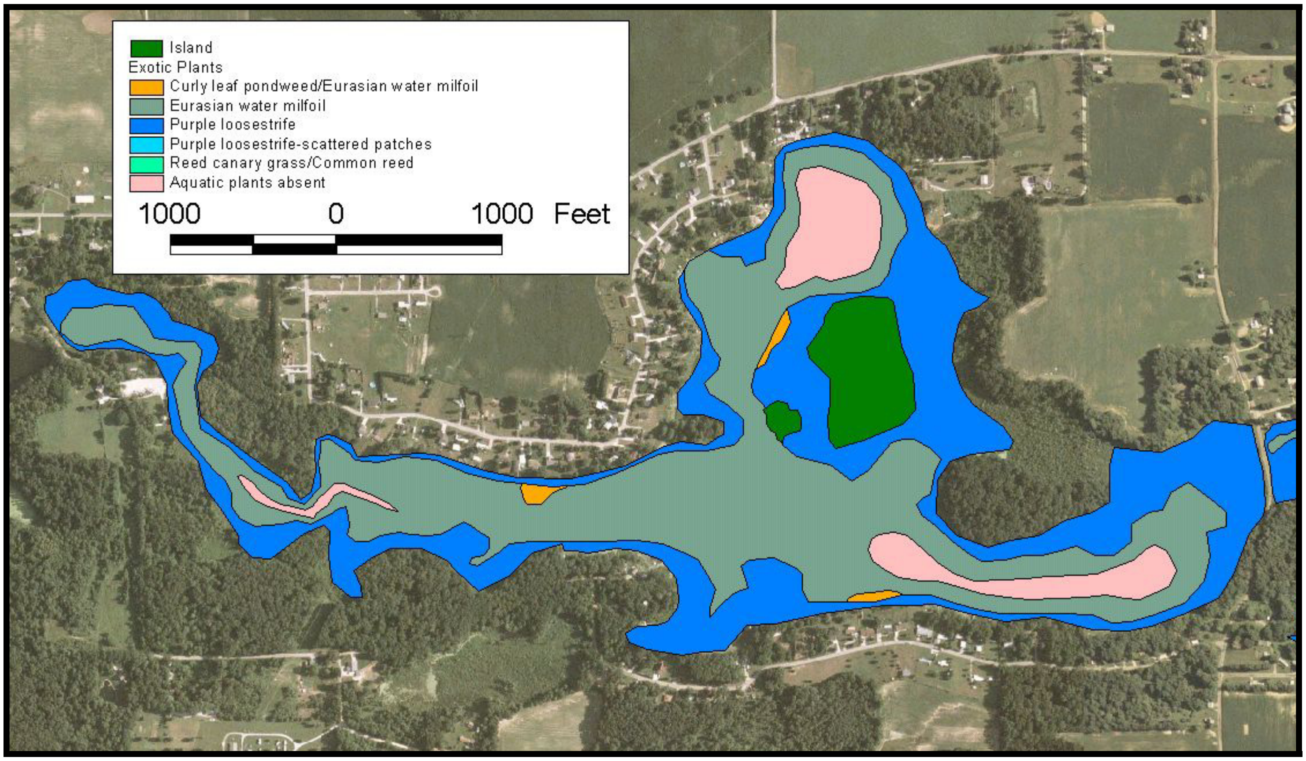

Figure 45. Exotic aquatic plant species locations within Kreighbaum and Millpond Lakes as mapped August 6, 2004.
Source: See Appendix A. Scale: 1"=1,200'.

There is some disagreement in the botanical community regarding the native versus exotic status of common reed. It is possible that some non-native strains of the species exist in northern Indiana. Regardless of whether the species is native or exotic, the species is a nuisance in northern Indiana. Like many of the other species discussed above, common reed has the potential to dominate a wetland or shoreline community to the exclusion of native species. Once established in a wetland, the species coverage often extends beyond the wetland limits. In fact, the species has been observed not only on the side slopes of roadside ditches in Michigan, but also trying to grow up through the road itself. In addition to lowering an area's diversity, common reed's woody structure provides poor habitat and serves as a poor food source compared to many of the emergents it replaces. The spread of this species in and around the Four Lakes could be very detrimental to the lakes' ecosystem.

The presence of Eurasian water milfoil and other exotics is typical in northern Indiana lakes. Of the lakes surveyed by aquatic plant control consultants and IDNR fisheries biologists, nearly every lake supported at least one exotic species (White, 1998a). In fact, White (1998a) notes the absence of exotics in only seven lakes in the 15 northern counties in Indiana. These 15 counties include all of the counties in northern Indiana where most of Indiana's natural lakes are located. Of the northern lakes receiving permission to treat aquatic plants in 1998, Eurasian water milfoil was listed as the primary target in those permits (White, 1998b). Despite the ubiquitous presence of nuisance species, lakeshore property owners and watershed stakeholders should continue management efforts to limit nuisance species populations. Management options will be discussed in further detail below.

4.5 Aquatic Plant Management Recommendations

The Four Lake's morphometry suggests that these lakes have the potential to possess extensive plant communities. In healthy lake, aquatic macrophytes typically vegetate shallow areas. Holem and Millpond Lakes are shallow by definition (maximum depth < 30 feet), and Cook and Kreighbaum Lakes possess extensive shallow areas. As indicated in Figures 12 and 18, water less than 5 feet (1.5 m) deep covers large areas of the lakes. Many of these areas are along shorelines and extend across travel lanes connecting the lakes. This prevalence of shallow areas in these lakes predisposes the lakes to supporting extensive plant communities. The estimated extent of the lakes' littoral zones is 54% (Cook Lake) to 94% (Millpond Lake).

While some lake residents might prefer a "plant free" lake, lake residents must remember that rooted plants play a variety of important roles in maintaining a healthy lake ecosystem. Rooted plants protect shorelines from erosion. They also add oxygen to a lake's water column enabling fish and other aquatic organisms to survive. Plants provide spawning, rearing, and cover habitat for a lake's fish community. They provide food for foraging waterfowl, amphibians, and small mammals. Rooted plants also stabilize lake bottoms and play a role in reducing in-lake turbidity. Research suggests that vegetation controls turbidity through a variety of mechanisms (Scheffer, 1998). Vegetation helps stabilize bottom sediments from wind and wave action. It provides a refuge for zooplankton, the primary predator of phytoplankton. Some rooted plant species can secrete allelopathic compounds (compounds that inhibit the growth of other plants) limiting algae growth. Similarly, rooted plants compete with algae for available nutrients and may affect the availability of nitrogen by creating conditions that facilitate denitrification (the conversion of nitrate to gaseous nitrogen). Given these many roles, rooted plants are an important component of a healthy, functioning lake ecosystem.

Rooted plants are particularly important in shallow lakes such as Holem and Millpond Lakes. In shallow lakes, many of the roles of rooted plants described above are responsible for keeping shallow lakes relatively clear and prohibiting the growth of algae populations. Disturbance to the plant communities in shallow lakes can cause shallow lakes to shift from a clear lake with extensive rooted plant growth to a turbid lake with dense algae populations. In other words, extensive removal of the rooted plants in shallow lakes often encourages algal growth and a resultant decrease in water clarity. This trade-off should be considered during the development of any aquatic plant management plan.

Development of an aquatic plant management plan that balances the ecological reality of the Four Lakes (i.e. that they are naturally shallow or possess extensive shallow areas) with the recreational goals of lake users is recommended for the Four Lakes. The plan should focus on control (or eliminating where feasible) the exotic and nuisance aquatic species in and around the lakes. Nuisance aquatic species typically out-compete native species, lowering the diversity of the ecosystem. Where rooted macrophytes interfere with desired uses of the lakes, limited, low-impact control should be considered. Areas where this type of control may be appropriate are along docks and piers and around beaches and boat ramps. Lake users should also remember that rooted plants are a vital part of a healthy functioning lake ecosystem; complete eradication of rooted plants is neither desirable nor feasible. A good aquatic plant management plan will reflect these facts. Aquatic plant management on the lakes should also include efforts to educate the public on the benefits of a healthy diverse rooted plant community and the ways in which the public can prevent the spread of nuisance species. Finally, IDNR fisheries biologists should be consulted when developing an aquatic plant management plan for these lakes. These biologists possess local knowledge, specifically knowledge regarding each lakes' quality and historical plant communities, that is invaluable for the creation of an aquatic plant management plan for Cook, Holem, Kreighbaum, and Millpond Lakes. While development of a complete aquatic plant management plan is beyond the scope of this diagnostic study, the following paragraphs include a list of recommendations that should form the foundation of any plan. A brief description of aquatic plant management techniques applicable to Cook, Holem, Kreighbaum, and/or Millpond Lakes follows the list.

Management Concerns within the Four Lakes

Cook, Holem, Kreighbaum, and Millpond Lakes possess structurally similar plant communities that are generally dominated by Eurasian water milfoil, coontail, watermeal, spatterdock, and purple loosestrife. Each lake also contains large areas of emergent plant growth or emergent wetlands that are likely helping to improve water quality within the lakes. These areas provide protection from wind mixing, which likely reduces the resuspension of bottom sediments and resultant nutrient loading. All efforts to maintain the structure and biotic diversity of these wetlands should be made. As detailed in the *Wetlands Section*, wetlands filter sediments and nutrients, provide water storage, and serve as habitat for various fish and wildlife species. All of these functions help to improve water quality and the biological health of streams and lakes located downstream of the wetlands. The two upstream lakes, Cook and Holem Lakes, contain sparser submerged plant communities than those present at Kreighbaum and Millpond Lakes. Poor water clarity likely contributes to the limited submerged plant growth in Holem Lake.

Cook, Holem, Kreighbaum, and Millpond Lakes exist as part of a larger chain of lakes. This chain includes Myers and Lawrence Lakes upstream and Lake Latonka downstream. Macrophyte surveys conducted on Myers and Lawrence Lakes on June 3, 1999 indicated that curly leaf pondweed and Eurasian water milfoil dominate the two lakes. Like residents at the Four Lakes, Myers and Lawrence Lake residents typically spot treat exotic species to provide better lake access and improve aesthetics (JFNew, 2000). Whole lake treatments to reduce or control Eurasian water milfoil or curly leaf pondweed populations have not been completed in either Myers or Lawrence Lakes (Jeremy Price, IDNR Fisheries Biologist, personal communication). Any aquatic plant management planning completed for the Four Lakes should account for the flow of fragmented plant material from Myers and Lawrence Lakes and the subsequent revegetation of these exotic, nuisance species within the Four Lakes. First and foremost, the Four Lakes Lake Association should work with the Myers Lake Association and the Lawrence Lake Association to complete aquatic plant management planning. Any subsequent herbicide application or large-scale treatment should include treatment of both lakes upstream of the Four Lakes to maximize the likelihood of exotic, nuisance species control within the chain of lakes.

With this in mind and because each of the lakes are utilized for slightly different purposes, goals of the plant management plan for each of the Four Lakes will likely be slightly different. The four primary concerns with the aquatic plant community present at the Four Lakes are the prevalence of filamentous algae, watermeal, and duckweed; the high density of coontail; the presence of Eurasian water milfoil; and the predominance of purple loosestrife along the shorelines. Any aquatic plant management plan for the lakes should include the following components to address these issues:

1. Implement watershed and in-lake management techniques to improve the lakes' water quality. The aquatic plant community reflects the nutrient concentrations in Cook, Holem, Kreighbaum, and Millpond Lakes. The presence of relatively dense populations of coontail, watermeal, and filamentous algae, all of which are species that can directly utilize nutrients from the water column, suggests that the lakes possess relatively high nutrient concentrations. In total, nine native pondweed species were identified within the Four Lakes during the current study. Kreighbaum and Millpond Lakes contained the highest pondweed diversity supporting eight pondweed species including large-leaf pondweed, leafy pondweed, grassy pondweed, Illinois pondweed, floating-leaf pondweed, long-leaf pondweed, sago pondweed, small pondweed, and flat-stem pondweed. Only long-leaf pondweed, small pondweed, and Illinois pondweed were identified within Holem Lake, while Cook Lake contained only sago pondweed and small pondweed. Most of the pondweed species identified within the Four Lakes exist in small stands throughout the lakes. Historical and current surveys of lakes in the region indicate that a much more diverse submerged aquatic plant community than was observed at Cook and Holem Lakes is possible. While it is not realistic to expect the presence of some of the rarer, more sensitive species, it is realistic to expect the growth of a more diverse submerged community including many of the species observed in Kreighbaum and Millpond Lakes. An improvement in Cook Lake's water quality and Holem Lake's water clarity might allow the return of these species, creating a more diverse and healthy submerged plant community.

2. In the undeveloped portions of the lakes, no aquatic plant management action is recommended other than treatment of aggressive nuisance and/or exotic species as outlined below. Holem Lake possesses the most dense and diverse emergent plant community of any of the Four Lakes. Cook, Kreighbaum, and Millpond Lakes possess moderately diverse, high density emergent plant communities within portions of the lakes. The emergent vegetation present along the much of the Four Lakes' lakeshore likely does not inhibit most recreational uses of the lakes. Residents along the Four Lakes should follow the example of residents along Holem Lake's northern shoreline. Emergent growth should only be removed at specific locations to provide access for piers or boats (Figure 46). Intact emergent plant growth along the Four Lakes shoreline will minimize the flow of nutrients and sediment from adjacent residential lawns to the lakes. With the exception of emergent exotic species such as purple loosestrife, common reed, and reed canary grass, as indicated below, removal of emergent plants is not recommended. Additional emergent plant treatment areas should be revisited during aquatic plant management plan development. If individual residents feel the amount of plant growth in front of their property is limiting the recreational potential of the lake, these residents

might consider management techniques such as spot treatment or hand harvesting of plant material and the use of bottom covers. (Please be aware that permits may be required for these activities. Residents should consult with the IDNR Division of Fish and Wildlife before implementing any of these management methods.)

Figure 46. Emergent shoreline present along Holem Lake's north shoreline.

3. Because the Four Lakes are primarily fishing lakes, any plant management efforts should manage the lakes' aquatic plant community to support fishing opportunities. Holem, Kreighbaum, and Millpond Lakes support extremely dense coontail population. The canopy coverage of this species rated 21 to 60% within each of these lakes' plant beds. Cook Lake contained a coontail population with a canopy coverage of 2 to 20%. Dense coontail populations can create an abundance of cover for prey fish (e.g. bluegills) to hide from predators. The result in situations like this is an explosion in panfish populations and consequent stunting of these fish due to increased competition for limited resources. Coontail populations have not yet reached maximum densities and the fish populations within the Four Lakes appear to be healthy. Four Lakes residents should continue to monitor coontail populations in conjunction with IDNR fisheries biologists to ensure continued good fishing on the Four Lakes.

4. Due to heavy growth of the submerged vegetative community along the developed shorelines of the lakes and within travel lanes between the lakes, specifically targeted aquatic plant management is recommended at this time in these areas (Figures 47 and 48). Problem areas within Cook and Holem Lakes include: the northwestern shoreline of Cook Lake, southwestern shoreline of Holem Lake, and the channels connecting Cook and Holem Lakes and Cook and Millpond Lakes. Likewise, problem areas identified in Kreighbaum and Millpond Lakes include: the bay northwest of the Millpond Lake boat ramp, and within the channels connecting Kreighbaum and Millpond Lakes and Millpond and Cook Lakes. These areas likely inhibit some recreational uses of the lakes. Individual residents identified the specific areas mapped in Figures 47 and 48 as the greatest areas of

concern for plant removal. These areas are the highest traffic areas within the lakes. Each area was also vegetated by Eurasian water milfoil at the time of the plant survey. Spot treatment within these areas will likely improve travel through these areas and reduce the spread of Eurasian water milfoil through fragmentation. However, spot treatment of these areas would need to be repeated on an annual or biannual basis, which could become quite costly. (Please be aware that permits may be required for these activities. Residents should consult with the IDNR Division of Fish and Wildlife before implementing any of these management methods.) An educational program highlighting the benefits a healthy plant community, including emergent species, might help residents make informed decisions on balancing their desire for relatively plant-free water in front of their property with the desire for a healthy, productive fish community in the lakes.

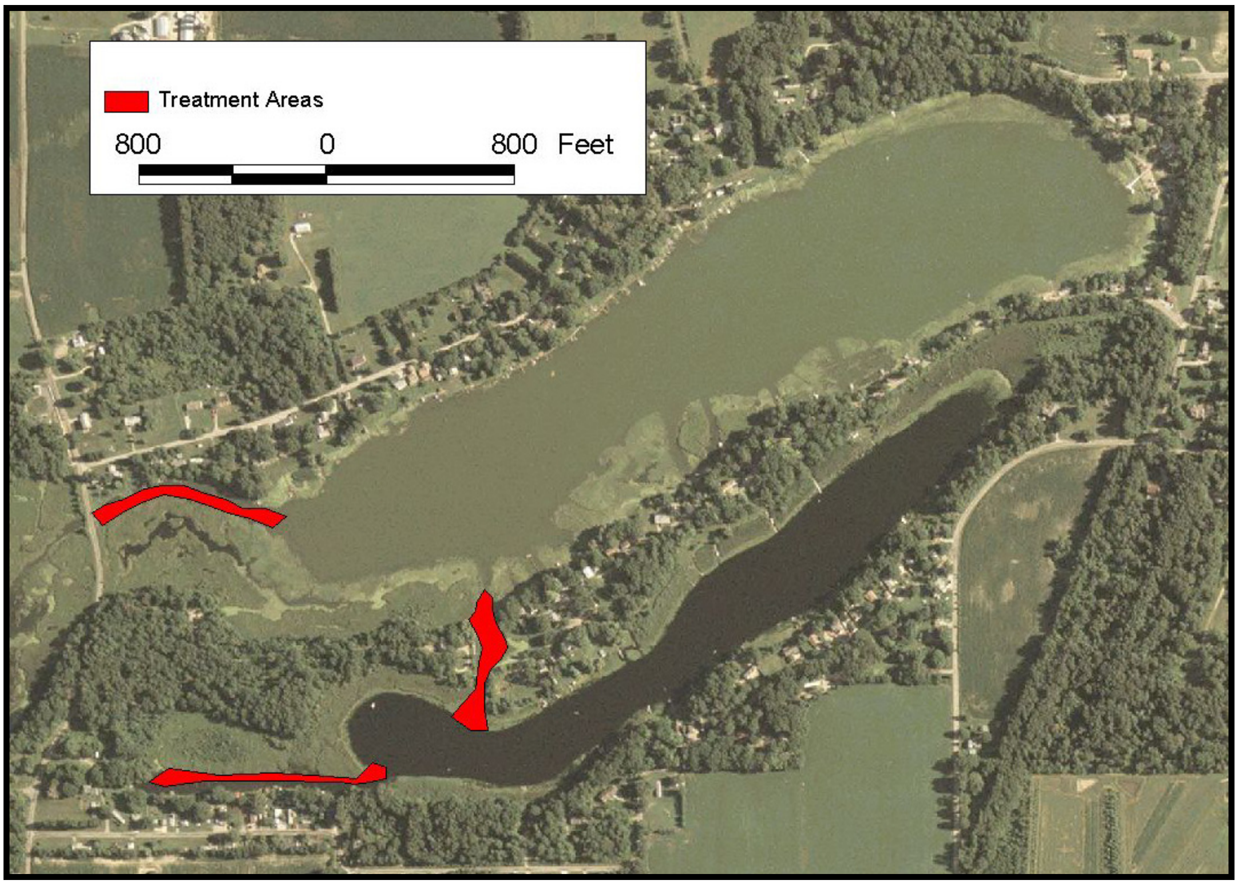

Figure 47. Priority aquatic plant treatment areas identified by residents for Cook and Holem Lakes.
Source: See Appendix A. Scale: 1”=800’.

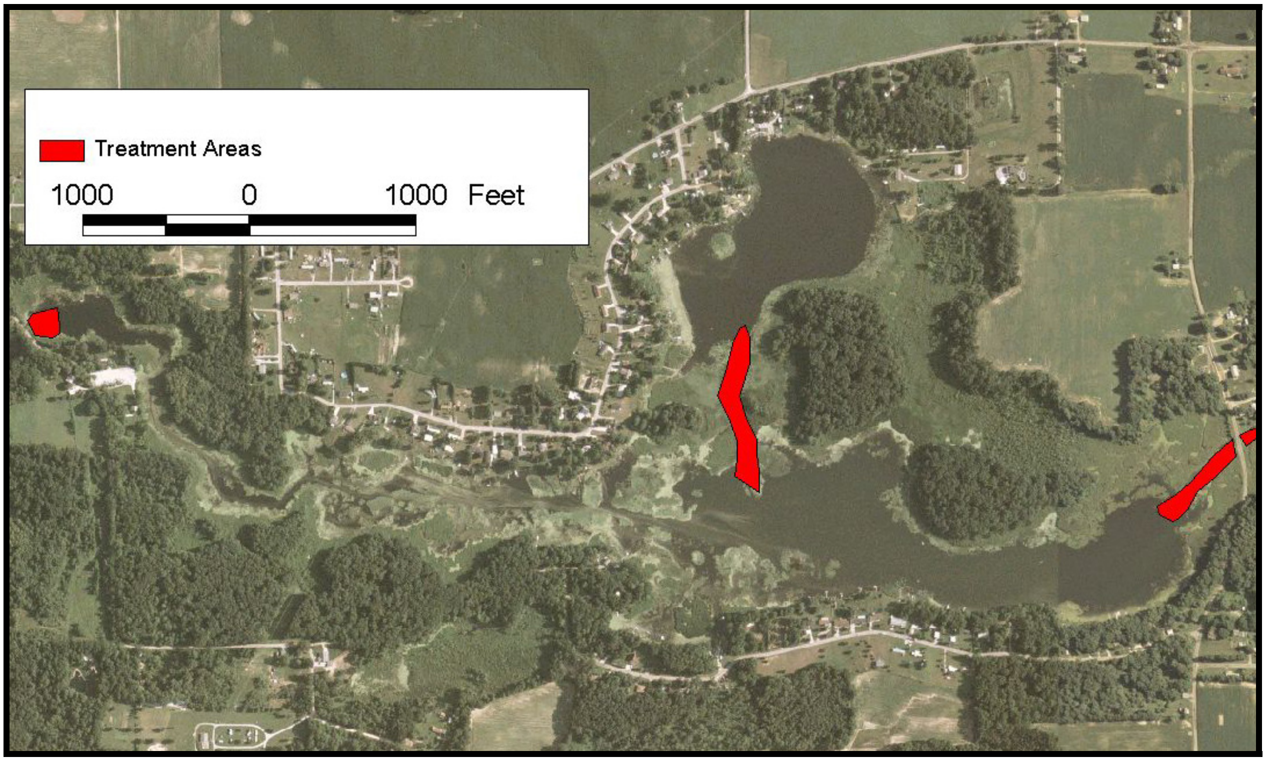

Figure 48. Priority aquatic plant treatment areas identified by residents for Kreighbaum and Millpond Lakes.
Source: See Appendix A. Scale: 1"=1,200'.

5. Take action to address the Eurasian water milfoil population in all of the Four Lakes. Eurasian water milfoil is especially dense throughout Kreighbaum and Millpond Lakes, and is present in lower densities within Cook and Holem Lakes. This species has the potential to proliferate and cover a large portion of the lakes. Eurasian water milfoil offers poor habitat to the lakes' inhabitants and often interferes with recreational uses of the lakes. Spot chemical treatments within Cook and Holem Lakes and the introduction of biological control agents into Kreighbaum and Millpond Lakes are management options that should be considered at this time to control the spread of the species within the Four Lakes. However, since exotic submerged species including Eurasian water milfoil and curly leaf pondweed cover large portions of the Four Lakes (Figures 44 and 45), a whole lake herbicide treatment should be considered. Any whole lake treatment must include Myers and Lawrence Lakes.

   Before completing a whole lake treatment, residents should be aware that the treatment will reduce the plant cover within the lakes; however, the removal of the plants and subsequent accumulation of organic material on the lakes' sediment will likely produce algal blooms within the Four Lakes. Additionally, plants will likely revegetate the shallow areas within the lakes due to their moderate transparency and readily available nutrients within the water column. The goal of the treatment would be to reduce the dominance of Eurasian water milfoil and curly leaf pondweed; therefore, the revegetation of shallow areas by native vegetation should be expected following the whole lake treatment. Residents should not begin spot treatments, introduction of biological agents, or whole lake treatments without consulting with the lake associations upstream of the Four Lakes and including those lakes in their plant management planning. Additionally, residents should consult with the IDNR Division of Fish and Wildlife before implementing any management methods.

Lake users should also educate themselves on the species. Taking precautionary measures such as ensuring that all plant material is removed from their boat propellers following their use prevents the spread of the species. Lake users should also refrain from boating through stands of Eurasian water milfoil. Pieces of the plant as small as one inch in length that are cut by a boat propeller as it moves through a stand of Eurasian water milfoil can sprout and establish a new plant. Signage at the Millpond Lake public boat ramp and information pamphlets at each of the campgrounds informing visitors of these best management practices would also be useful. It is important to note that IDNR approval is required to post any signs at the public boat ramp.

6. Continue to address the purple loosestrife population along the lakes' shoreline. Biological control agents specific to purple loosestrife were introduced along Cook Lake's southern shoreline in 2001. The exotic species cover map (Figure 44) suggests that purple loosestrife plants are more sparse within and adjacent to the release sites than around the remainder of Cook Lake. The introduction of additional biological control insects at multiple sites around the lakes could speed the spread of purple loosestrife control around the Four Lake. (Please be aware that permits may be required for these activities. Residents should consult with the IDNR Division of Fish and Wildlife and IDNR Division of Nature Preserves before implementing any of these management methods.) Additionally, hand removal or spot treatment of individual purple loosestrife plants along individual properties will also reduce the spread of purple loosestrife along the shoreline of the Four Lakes. Residents along Cook Lake's southern shoreline should not spot treat large stands of purple loosestrife because the chemical treatment could interfere with or harm the biological treatment already in progress. An educational program highlighting the benefits of a healthy plant community and the identification of purple loosestrife might help residents make informed decisions on balancing their desire for relatively plant-free water in front of their property with the desire for a healthy, productive fish community in the lakes.

7. Treat the common reed and reed canary grass populations present along Holem Lake's southern shoreline. These species are exotic, invasive species that spread rapidly through emergent wetland communities creating a monoculture which excludes native wetland and shoreline plants. This limits a wetland's diversity ultimately impacting the wetland's functions. Because the populations identified at Holem Lake remain relatively isolated, spot treatment is likely the best management practices for control and removal of these plants. These species should be targeted immediately before they spread to other areas along the Four Lakes' shoreline.

The following is a brief description of aquatic plant management techniques recommended in the list above. A good aquatic plan management plan includes a variety of management techniques applicable to different parts of a lake depending on the lake's water quality, the characteristics of the plant community in different parts of the lake, and lake users' goals for different parts of the lake. Many aquatic plant management techniques, including chemical control, harvesting, and biological control require a permit from the IDNR. Depending on the size and location of the treatment area, even individual residents may need a permit to conduct a treatment. Residents should contact the IDNR Division of Fish and Wildlife before conducting any treatment.

4.5.1 Chemical Control

Herbicides are the most traditional means of controlling aquatic vegetation. Herbicides have been used in the past on the Four Lakes. Richard Soper of Pine Crest Industries has treated Cook, Holem, Kreighbaum, and Millpond Lakes for over fifteen years including five of the last six years. (None of the Four Lakes were treated with aquatic herbicide during 2001.) Mr. Soper reports little overall change in the species composition but an overall increase in plant biomass over the last fifteen years. He points out that the conditions in the Four Lakes, namely a silty substrate, relatively clear water, and low external nutrient inputs (as perceived by Mr. Soper), are ideal for the growth of Eurasian water milfoil and curly leaf pondweed. Mr. Soper also noted that the shallow nature of Holem and Millpond Lakes and portions of Cook and Kreighbaum Lakes contribute to plant growth within these lakes.

During the past six years, Eurasian water milfoil, curly leaf pondweed, and chara are the primary targeted species within Cook Lake. Reward (diquat), Komeen (copper-based herbicide), and Clearigate (chelated copper) were applied to 5.6 acres (2.3 ha) and copper sulfate was used to treat an additional 2 acres (0.8 ha) of Cook Lake. The primary areas of treatment within Cook Lake were the channel in the northwest corner of the lake and individual piers and swimming areas along the northern and southern shorelines. IDNR aquatic vegetation permit applications filed over the past six years indicate that, with the exception of 2001, the channel in the northwest corner of the lake has received aquatic herbicide treatment annually. Over the six year period, almost the entire northern shoreline and approximately half of the southern shoreline have been treated to control the above listed species.

Aquatic plant treatment methods utilized within Holem Lake are similar to those used in Cook Lake. Richard Soper of Pine Crest Industries treated the same 3 acres (1.2 ha) within Holem Lake for five of the past six years. Target areas included the channel in the southeastern corner of the lake and two individual residences located along the northern shoreline and within the channel connecting Holem Lake to Cook Lake. Reward, Komeen, and Clearigate were applied to targeted curly leaf pondweed and coontail populations. Copper sulfate was also applied to treat 1 acre (0.4 ha) of chara within the target areas.

Treatment methods for aquatic plants within Kreighbaum and Millpond Lakes were similar to those for Cook and Holem Lakes. Richard Soper of Pine Crest Industries utilized Reward, Komeen, and Clearigate target curly leaf pondweed, coontail, and Eurasian water milfoil populations and copper sulfate to treat filamentous algae within Kreighbaum and Millpond Lakes. Over the past six years the treatment area has increased within Kreighbaum Lake. Prior to 2002, less than 1 acre (0.4 ha) along the northern shoreline of Kreighbaum Lake was treated for curly leaf pondweed and Eurasian water milfoil. Treatment increased to cover nearly 4.5 acres (1.8 ha) in 2003 and 2004 resulting in nearly the entire portion of the developed shoreline of Kreighbaum Lake being treated with aquatic herbicide over the last six years. Treatment areas around Millpond Lake have varied over the past six years. Approximately 1.4 acres (0.6 ha) along the southern shoreline of Millpond Lake was treated in 1999. Nearly 6 acres (2.4 ha) of coontail, Eurasian water milfoil, and curly leaf pondweed and 4 acres (1.6 ha) of filamentous algae were treated along the northwestern and southern shorelines of the lake in 2002. A total of 3.7 acres (1.5 ha) covering similar locations and the northwestern bay of Millpond Lake were treated in 2003 and 2004.

In addition to these large scale applications, it is likely that some residents may have conducted their own spot treatments around piers and swimming areas. It is important for residents to remember that any chemical herbicide treatment program should always be developed with the help of a certified applicator who is familiar with the water chemistry of a targeted lake. In addition, application of a chemical herbicide may require a permit from the IDNR, depending on the size and location of the treatment area. Information on permit requirements is available from the IDNR Division of Fish and Wildlife or conservation officers.

Herbicides vary in their specificity to given plants, method of application, residence time in the water and the use restrictions for the water during and after treatments. Herbicides (and algaecides; chara is an algae) that are non-specific and require whole lake applications to work are generally not recommended. Such herbicides can kill non-target plant and sometimes even fish species in a lake. Costs of an herbicide treatment vary from lake to lake depending upon the type of plant species present in the lake, the size of the lake, access availability to the lake, the water chemistry of the lake, and other factors. Typically, in northern Indiana costs for treatment range from $300 to $400 per acre or $750 to $100 per hectare (Cecil Rich, IDNR, personal communication).

A multitude of compounds provide effective plant treatment. The effectiveness of any chemical often depends upon the water chemistry of the lake in which it is applied. For example, while 2,4-D may typically be effective in controlling Eurasian water milfoil, it is typically ineffective in lakes with low pH and high hardness, like Myers Lake. Typically, lake managers utilize one of three herbicides in the control of Eurasian water milfoil: 2,4-D, diquat, and fluridone. Aquatic applicators utilize 2,4-D to selectively target broad-leaf plants such as Eurasian and native water milfoils and coontail. 2,4-D is a highly selective chemical which leaves pondweeds and other native species unaffected by the treatment. It is a systemic aquatic herbicide which is absorbed into plants and transported through their vascular system, affecting remote parts of the plant such as leaves, shoots, and roots. Doses of 50 to 150 pounds per acre are typically utilized to treat aquatic plants (Holdren et. al, 2001). Application should occur in early spring after the plants are active and growing, but before winter buds are formed. Like 2,4-D, diquat provides short-term exposure. Diquat typically produces results within two weeks of treatment occurring. Diquat can be less effective than 2,4-D or fluridone and some species can regrow within the year. Concentrations of diquat required for treatment are also higher than those for fluridone but should not exceed 2 mg/L (Holdren et. al, 2001).

Fluridone is a nonselective systemic aquatic herbicide. It requires very long exposure times from several weeks to several months. Research indicates that fluridone is typically effective and selective at very low concentrations (Smith and Pullman, 1997). For example, treated water possessing a concentration of 20 ppb is effective on Eurasian water milfoil, but many natives are not affected at this low dose. Fluridone appears to work best where the entire water body can be treated, but not in spot treatments or high water exchange areas (Madsen, 2000). Because of its slow activity rate fluridone provides gradual breakdown of plants resulting in a more gradual release of nutrients from plant material than other aquatic herbicides. Fluridone is very expensive (>$1,000/gallon) and it should be applied only by highly experienced applicators. Application requires a bioassay of plants to determine the effective concentration and careful monitoring of the concentration in the water (Mark Mongin, SePro, personal communication).

While providing a short-term fix to the nuisances caused by aquatic vegetation, chemical control is not a lake restoration technique. Herbicide and algaecide treatments do not address the reasons why there is an aquatic plant problem, and treatments need to be repeated each year to obtain the desired control. In addition, some studies have shown that long-term use of copper sulfate (algaecide) has negatively impacted some lake ecosystems. Such impacts include an increase in sediment toxicity, increased tolerance of some algae species, including some blue-green (nuisance) species, to copper sulfate, increased internal cycling of nutrients and some negative impacts on fish and other members of the food chain (Hanson and Stefan, 1984 cited in Olem and Flock, 1990).

Chemical treatment should be used with caution on any of the study lakes since treated plants are often left to decay in the water. This will contribute nutrients to the lakes' water columns which already possesses high levels of nutrients. Additionally, plants left to decay in the water column will consume oxygen. The in-lake sampling conducted during this study showed the water columns in Cook, Holem, and Kreighbaum Lakes were less than 40% oxic. Added oxygen demand in these lakes will further reduce the already low volume of lake water with sufficient oxygen to support fish.

4.5.2 Mechanical Harvesting

Harvesting involves the physical removal of vegetation from lakes. Like chemical control, harvesting should also be viewed as a short-term management strategy. Harvesting needs to be repeated yearly and sometimes several times within the same year. (Some carry-over from the previous year has occurred in certain lakes.) Despite this, harvesting is often an attractive management technique because it can provide lake users with immediate access to areas and activities that have been affected by excessive plant growth. Mechanical harvesting is also beneficial in situations where removal of plant biomass will improve a lake's water chemistry. (Chemical control leaves dead plant biomass in the lake to decay and use up valuable oxygen.)

Macrophyte response to harvesting often depends upon the species of plant and particular way in which the management technique is performed. Pondweeds, which rely on sexual reproduction for propagation, can be managed successfully through harvesting. However, many harvested plants, especially milfoil, can re-root or reproduce vegetatively from the cut pieces left in the water. Plants harvested several times during the growing season, especially late in the season, often grow more slowly the following season (Cooke et al., 1993). Harvesting plants at their roots is usually more effective than harvesting higher up on their stems (Olem and Flock, 1990). This is especially true with Eurasian water milfoil and curly leaf pondweed. Benefits are also derived if the cut plants and the nutrients they contain are removed from the lake. Harvested vegetation that is cut and left in the lake ultimately decomposes, contributing nutrients and consuming oxygen.

The cost of the harvester is typically the largest single outlay of money involved with this plant management technique. Depending upon the capacity of the harvester, costs can range from $3,500 to over $100,000 (Cooke et al., 1993). Other costs associated with harvesting include labor, disposal site availability and proximity, amortization rate, size of lake, density of plants, reliability of the harvester, and other factors. Depending upon the specific situation, harvesting costs can range from $200 to over $1,500 per acre (Adams, 1983; Prodan, 1983; Holdren et al., 2001). Estimated costs of the mechanical harvesting program at Lake Lemon in Bloomington, Indiana averaged $267 per acre ($659 per hectare, Zogorski et al., 1986). In general, however, excluding the cost of the machine, the cost of harvesting is comparable to that for chemical control (Cooke et al., 1993; Olem and Flock, 1990).

Given the dominance of coontail and Eurasian water milfoil throughout Cook, Holem, Kreighbaum, and Millpond Lakes, large scale mechanical harvesting may not make economic sense on these lakes. Large scale harvesting should be avoided in areas dominated by Eurasian water milfoil. When small fragments of Eurasian water milfoil break off, they are capable of sprouting roots and becoming established as an individual plant. Large scale harvesting efforts often create many small fragments of plants despite vigilant efforts to capture all cut plant material. Thus, the benefits derived from harvesting (reduction of plant density and removal of potential source of nutrients) Eurasian water milfoil may not outweigh the risks of spreading the species throughout the lakes. The cost of large scale harvesting on the Four Lakes will likely be too great for consideration by the lake association. Additionally under new regulations, any large scale harvesting operations will require a permit from the IDNR Division of Fish and Wildlife.

4.4.3 Hand Harvesting

Hand harvesting may be the best option to manage aquatic plants in small areas where human uses are hampered by extensive growths (docks, piers, beaches, boat ramps). In these small areas, plants can be efficiently cut and removed from the lake with hand cutters such as the Aqua Weed Cutter (Figure 49). In less than one hour every two to three weeks, a homeowner can harvest ‘weeds’ from along docks and piers. Depending on the model, hand-harvesting equipment for smaller areas costs from $50 to $1500 (McComas, 1993). To reduce the cost, several homeowners can invest together in such a cutter. Alternatively, a lake association may purchase one for its members. This sharing has worked on other Indiana lakes with aquatic plant problems. Use of a hand harvester is more efficient and quick-acting, and less toxic for small areas than spot herbicide treatments. Depending on the size to be treated, a permit may be required for hand-harvesting. (The IDNR Division of Fish & Wildlife can assist lake residents in determining whether a permit is needed and how to obtain one.)

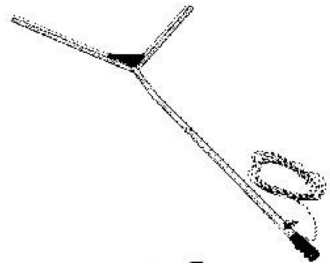

Figure 49. An aquatic weed cutter designed to cut emergent weeds. It has a 48” cutting width, uses heavy-duty stainless steel blades, can be sharpened, and comes with an attached 20’ rope and blade covers.

4.5.4 Biological Control

Biological control involves the use of one species to control another species. Often when a plant species that is native to another part of the world is introduced to a new country with suitable habitat, it grows rapidly because its native predators have not been introduced to the new country along with the plant species. This is the case with some of the common pest plants in northeast Indiana such as Eurasian water milfoil and purple loosestrife. Neither of these species is native to Indiana, yet both exist within all of the lakes in the watershed. (See the *Aquatic Macrophyte Results Section* and the Myers-Lawrence Diagnostic Study, completed by JFNew in 2000, for more detailed information on locations of these plants in the watershed.)

Researchers have studied the ability of various insect species to control both Eurasian water milfoil and purple loosestrife. Cooke et al. (1993) points to four different species that may reduce Eurasian water milfoil infestations: *Triaenodes tarda*, a caddisfly, *Cricotopus myriophylii*, a midge, *Acentria nivea*, a moth and *Litodactylus leucogaster*, a weevil. Recent research efforts have focused on the potential for *Euhrychiopsis lecontei*, a native weevil, to control Eurasian water milfoil. Purple loosestrife biocontrol researchers have examined the potential for three insects, *Gallerucella calmariensis*, *G. pusilla*, and *Hylobius transversovittatus,* to control the plant. The following paragraphs contain information that will allow Four Lakes’ residents to understand the common biocontrol mechanisms for these two species. Residents should be aware that under new regulations an IDNR permit is required for the implementation of a biological control program on a lake.

Eurasian Water milfoil

Euhrychiopsis lecontei has been implicated in a reduction of Eurasian water milfoil in several Northeastern and Midwestern lakes (EPA, 1997). *E. lecontei* weevils reduce milfoil biomass by two means: one, both adult and larval stages of the weevil eat different portions of the plant and two, tunneling by weevil larvae cause the plant to lose buoyancy and collapse, limiting its ability to reach sunlight. The weevils’ actions also cut off the flow of carbohydrates to the plant’s root crowns impairing the plant’s ability to store carbohydrates for over wintering (Madsen, 2000). Techniques for rearing and releasing the weevil in lakes have been developed and under appropriate conditions, use of the weevil has produced good results in reducing Eurasian water milfoil. A nine-year study of nine southeastern Wisconsin lakes suggested that weevil activity might have contributed to Eurasian water milfoil declines in the lakes (Helsel et al., 1999). The Indiana Department of Natural Resources is conducted field trials on three Indiana lakes, although results from the trials are not yet available.

Cost effectiveness and environmental safety are among the advantages to using the weevil rather than traditional herbicides in controlling Eurasian water milfoil (Christina Brant, EnviroScience, personal communication). Cost advantages include the weevil's low maintenance and long-term effectiveness versus the annual application of an herbicide. In addition, use of the weevil does not have application restrictions that are required with some chemical herbicides. Use of the weevil has a few drawbacks. The most important one to note is that reductions in Eurasian water milfoil are seen over the course of several years in contrast to the immediate response seen with traditional herbicides. Therefore, lake residents need to be patient. Additionally, the weevils require natural shorelines for over-wintering. The prevalence of natural shoreline along most of the Four Lakes would make these lakes good candidates for treatment with the weevils if the Eurasian water milfoil population in that lake expands. The IDNR released *E. lecontei* weevils in three Indiana lakes to evaluate the effectiveness of utilizing the weevils to control Eurasian water milfoil in Indiana lakes. The results of the study were inconclusive (Scribailo and Alix, 2003) and the IDNR considers the use of weevils in Indiana lakes an unproven technique and only experimental (Rich, 2005). Four Lakes residents should take this into account before attempting treatment of the lakes' Eurasian water milfoil with *E. lecontei* weevils.

Purple Loosestrife

Biological control may also be possible for controlling the growth and spread of the emergent purple loosestrife. Like Eurasian water milfoil, purple loosestrife is an aggressive non-native species. Once purple loosestrife becomes established in an area, the species will readily spread and take over the habitat, excluding many of the native species which are more valuable to wildlife. Conventional control methods, including mowing, herbicide applications, and prescribed burning, have been unsuccessful in controlling purple loosestrife.

Some control has been achieved through the use of several insects. A pilot project in Ontario, Canada reported a decrease of 95% of the purple loosestrife population from the pretreatment population (Cornell Cooperative Extension, 1996). Four different insects were utilized to achieve this control. These insects have been identified as natural predators of purple loosestrife in its native habitat. Two of the insects specialize on the leaves, ultimately defoliating a plant (*Gallerucella calmariensis* and *G. pusilla*); one specializes on the flower, while one eats the roots of the plant (*Hylobius transversovittatus*). Insect releases in Indiana to date have had mixed results. After six years, the loosestrife of Fish Lake in LaPorte County is showing signs of deterioration. Likewise, seven years after the release of *Gallerucella* at Pleasant Lake in St. Joseph County, purple loosestrife populations appear to have declined around the boat ramp (IDNR, 2004b). Biological control is not a short-term solution; current estimates suggest that it takes 5 to 15 years to achieve a large impact on purple loosestrife populations (Klepinger et. al, 2001).

Like biological control of Eurasian water milfoil, use of purple loosestrife predators offers a cost-effective means for achieving long-term control of the plant. Complete eradication of the plant cannot be achieved through use of a biological control. Insect (predator) populations will follow the plant (prey) populations. As the population of the plant decreases, so will the population of the insect since their food source is decreasing. Ultimately, purple loosestrife experts hope that biological control will reduce purple loosestrife densities by 90% (Klepinger et. al, 2001).

Biological control efforts have occurred at more than 40 sites within Marshall County. Many of the release sites, including portions of the Menominee State Wetland Conservation Area, are located near the Four Lakes. One release of approximately 4,500 *Gallerucella* occurred at Cook Lake on June 21, 2001 (Rich Dunbar, IDNR Division of Nature Preserves, personal communication). The insects have not noticeably impacted purple loosestrife populations at Cook Lake. However, sparse purple loosestrife populations along Cook Lake's southern shoreline (Figure 44) compared to the shorelines along the rest of the Four Lakes may indicate that the insects are negatively impacting the purple loosestrife population. As the insects have only been in residence for three years, it is still too early to determine the ultimate impact of the release. Additional releases at Cook, Holem, Kreighbaum, and Millpond Lakes have been discussed for the future (Cheryl Rhoades, Lake County 4-H Coordinator, personal communication).

Because of the extent of purple loosestrife along the study lakes, management should include several techniques, such as biological control, chemical control, and hand removal of the species. Lake residents should also be taught to identify purple loosestrife so that they can manage their own shorelines. Given the relative size and overall distribution of the species, release of a biological control agent would likely be the most cost effective measure at this time. Residents should be aware that biological control is a long-term investment and will not result in immediate reductions in the purple loosestrife population around Cook, Holem, Kreighbaum, and Millpond Lakes.

4.5.5 Bottom covers

Bottom shading by covering bottom sediments with fiberglass or plastic sheeting materials provides a physical barrier to macrophyte growth. Buoyancy and permeability are key characteristics of the various sheeting materials. Buoyant materials (polyethylene and polypropylene) are generally more difficult to apply and must be weighted down. Unfortunately, sand or gravel anchors used to hold buoyant materials in place can act as substrate for new macrophyte growth. Any bottom cover materials placed on the lake bottom must be permeable to allow gases to escape from the sediments; gas escape holes must be cut in impermeable liners. Commercially available sheets made of fiberglass-coated screen, coated polypropylene, and synthetic rubber are non-buoyant and allow gases to escape, but cost more (up to $66,000 per acre or $163,000 per hectare for materials, Cooke and Kennedy, 1989). Indiana regulations specifically prohibit the use of bottom covering material as a base for beaches.

Due to the prohibitive cost of the sheeting materials, sediment covering is recommended for only small portions of lakes, such as around docks, beaches, or boat mooring areas. This technique may be ineffective in areas of high sedimentation, since sediment accumulated on the sheeting material provides a substrate for macrophyte growth. The IDNR requires a permit for any permanent structure on the lake bottom, including anchored sheeting.

4.5.6 Preventive Measures

Preventive measures are necessary to curb the spread of nuisance aquatic vegetation. Although milfoil is thought to 'hitchhike' on the feet and feathers of waterfowl as they move from infected to uninfected waters, the greatest threat of spreading this invasive plant is humans. Plant fragments snag on boat motors and trailers as boats are hauled out of lakes (Figure 50). Milfoil, for example, can survive for up to a week in this state; it can then infect a milfoil-free lake when the boat and trailer are next launched. It is important to educate boaters to clean their boats and trailers of all plant fragments each time they retrieve them from a lake.

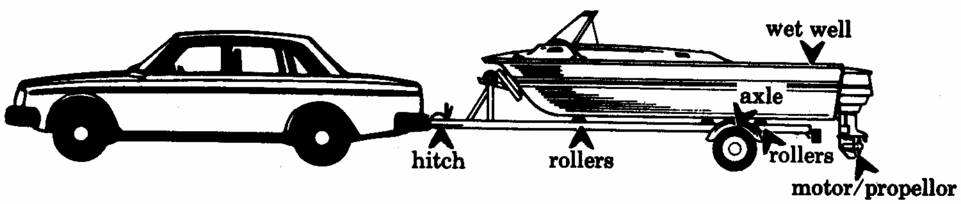

Figure 50. Locations where aquatic macrophytes are often found.

Educational programs are effective ways to manage and prevent the spread of aquatic nuisance species (ANS) such as Eurasian water milfoil, zebra mussels, and others. Of particular help are signs at boat launch ramps asking boaters to check their boats and trailers both before launching and after retrieval. All plants should be removed and disposed of in refuse containers where they cannot make their way back into the lake. The Illinois-Indiana Sea Grant Program has examples of boat ramp signs and other educational materials that can be used at the Four Lakes. Although Eurasian water milfoil already exists in the study lakes, educational programs and lake signage will help prevent the spread of this nuisance species to other lakes. This is particularly important at Cook, Holem, Kreighbaum, and Millpond Lakes. Since many individuals temporarily residing at the campgrounds around the lakes and those fishing on the lakes on a short-term basis launch their boats at other lakes, these lake users are extremely likely to use their boats in other lakes in addition to the Four Lakes. Signs addressing any best management practices to prevent the spread of nuisance aquatic species will ultimately help Cook, Holem, Kreighbaum, and Millpond Lakes as new nuisance (often non-native) species are finding their way to Indiana lakes all the time. Permission must be obtained from the IDNR Division of Fish and Wildlife before posting any signage at a public boat launch.

5.0 FISHERIES

Cook, Holem, Kreighbaum, and Millpond Lakes share very similar fisheries due to their proximity and connection to one another. The Indiana Department of Natural Resources considers Cook and Holem Lakes a single lake from a fisheries management perspective. The same is also true of Kreighbaum and Millpond Lakes. Fish are able to migrate freely in each of the associated lakes (Cook-Holem and Kreighbaum-Millpond), which are more like sub-basins within one lake rather than two separate lakes.

5.1 Cook and Holem Lakes

The IDNR conducted its first fishery survey on Cook and Holem Lakes in 1970. Prior to this, limited fisheries management information existed for the lakes (Robertson, 1971). The IDNR conducted follow up studies in 1976 and 2002.

Cook and Holem Lakes possess a moderately diverse fish community with IDNR fisheries biologists collecting 19 species representing 9 families over the course of three surveys (Table 48). (The total number of species listed in Table 48 is 20; however, the unidentified killifish present during the 1970 survey was likely a starhead topminnow. This hypothesis is based on similarities between these species and the collection of the starhead topminnow during the 2002 survey.) In 1970, 16 species (not including the killifish) were collected by the IDNR. Bluegill, redear sunfish, lake chubsucker, and largemouth bass dominated the catch. Three of the observed species were represented by a single individual. Only 13 species were collected during the 1976 survey of Cook and Holem Lakes. Bluegill accounted for approximately 48% of the fish community, while redear sunfish and largemouth bass represented 16% and 13% of the community, respectively. During the 2002 survey, 18 species were collected from Cook and Holem Lakes. Bluegill accounted for nearly 70% of the fish community. Ten species were represented by 10 or fewer individuals.

Table 48. Fish species collected during IDNR surveys of Cook and Holem Lakes.

Common Name	Scientific Name	1970	1976	2002
Black Bullhead	*Ameiurus melas*			X
Black Crappie	*Pomoxis nigromaculatus*	X	X	X
Bluegill	*Lepomis macrochirus*	X	X	X
Bowfin	*Amia calva*	X	X	X
Brook Silverside	*Labidesthes sicculus*		X	X
Brown Bullhead	*Ameiurus nebulosus*	X	X	X
Darter	--	X		
Golden Shiner	*Notemigonous crysoleucas*	X	X	X
Grass Pickerel	*Esox americanus*	X	X	X
Hybrid sunfish	*Lepomis sp. x Lepomis sp.*	X		X
Killifish	*Fundulus sp.*	X		
Lake Chubsucker	*Erimyzon sucetta*	X	X	X
Largemouth Bass	*Micropterus salmoides*	X	X	X
Pumpkinseed	*Lepomis gibbosus*	X		X
Redear Sunfish	*Lepomis microlophus*	X	X	X
Starhead Topminnow	*Fundulus dispar*			X
Warmouth	*Lepomis gulosus*	X	X	X
White Crappie	*Pomoxis annularis*	X		X
Yellow Bullhead	*Ameiurus natalis*	X	X	X
Yellow Perch	*Perca flavescens*	X	X	X

As is typical of Indiana lakes, sunfish dominated the Holem and Cook Lake fishery during all surveys accounting for 7 species identified within Cook and Holem Lakes. Bluegill was the most prevalent component comprising nearly 34% of the community composition in 1970, 48% in 1976, and 71% in 2002 (Figure 51). The reason for the increase in bluegill percent composition over the years is unclear. It may be due to changes in harvest rates, year class strength, or a number of other factors. Combined with redear sunfish and largemouth bass, these three species account for nearly 80% of the lakes' fish community by number. Non-game fish species are minor contributors to the lakes' fish community. Lake chubsucker and golden shiner, the most prevalent non-game species, only represent 3 to 13% of the community by number on an annual basis. However, these non-game species are important forage components for largemouth bass.

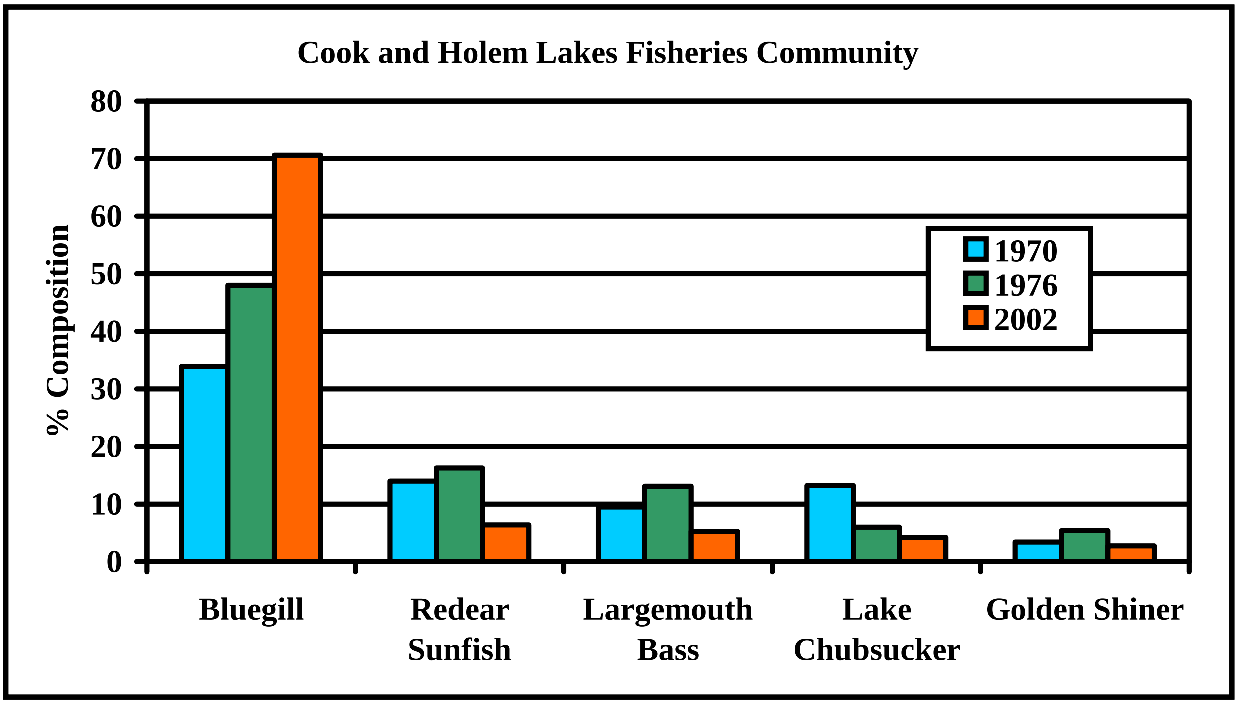

Figure 51. Percent community composition for Cook and Holem Lakes.
Source: Robertson, 1971; Robertson, 1977; Price and Robertson, 2003.

In general, Cook and Holem Lakes support a healthy gamefish population. Growth rates for many of these species are near or above district averages (Price and Robertson, 2003). The presence of several year classes for species such as bluegill, redear sunfish, and largemouth bass indicate a healthy community. Problematic fish species such as common carp and gizzard shad have not been collected during the IDNR fishery surveys. When introduced to a lake, these species often negatively impact the native fish community by competing for valuable food resources or reducing water clarity as a result of their foraging habits as is the case with the common carp. Price and Robertson (2003) emphasize the importance of preventing the introduction of unwanted species to maintain Holem and Cook Lakes' fisheries.

5.2 Kreighbaum and Millpond Lakes

The IDNR conducted its first fisheries survey of Kreighbaum and Millpond Lakes in 1980. The IDNR surveyed Kreighbaum and Millpond Lakes again in 2003. A total of 16 species representing 7 families was collected by the IDNR during these surveys (Table 49). Centrachids (sunfish) and Catastomids (suckers) were well represented by numerous species and individuals within the lakes' fish community. Some genera within these families were represented by only a few individuals. In 1980, bluegill was the most prevalent species by number accounting for nearly 48% of the total catch followed by lake chubsucker (11%), redear sunfish (8%), and yellow perch (8%). In total, 16 species were collected by the IDNR in 1980. In 2003, 13 species were collected from Kreighbaum and Millpond Lakes' fish community. Bluegill again composed the largest portion of the fish community accounting for approximately 53% of the total catch by number. Redear sunfish and largemouth bass represented 16% and 9% of the community, respectively.

Table 49. Fish species collected during IDNR surveys of Kreighbaum and Millpond Lakes.

Common Name	Scientific Name	1980	2003
Black Crappie	*Pomoxis nigromaculatus*	X	X
Bluegill	*Lepomis macrochirus*	X	X
Bowfin	*Amia calva*	X	X
Brook Silverside	*Labidesthes sicculus*	X	X
Brown Bullhead	*Ameiurus nebulosus*	X	X
Golden Shiner	*Notemigonous crysoleucas*	X	X
Grass Pickerel	*Esox americanus*	X	X
Hybrid Sunfish	*Lepomis sp. x Lepomis sp.*	X	
Lake Chubsucker	*Erimyzon sucetta*	X	X
Largemouth Bass	*Micropterus salmoides*	X	X
Pumpkinseed	*Lepomis gibbosus*	X	X
Redear Sunfish	*Lepomis microlophus*	X	X
Warmouth	*Lepomis gulosus*	X	X
Yellow Bullhead	*Ameiurus natalis*	X	
Yellow Perch	*Perca flavescens*	X	X
Longear Sunfish	*Lepomis megalotis*	X	

Overall, the sunfish family dominated Kreighbaum and Millpond Lakes. Bluegill, the most abundant sunfish, accounted for nearly 50% of the fish community during each survey (Figure 52). In 2003, both redear sunfish and largemouth bass percent composition increased from 1980 levels. Although non-game species populations, such as lake chubsucker and golden shiner, appear relatively stable, they declined slightly from 1980 to 2003. Much like the community present within Cook and Holem Lakes, non-game fish species appear to be a minor component of the Kreighbaum and Millpond Lakes fishery. Several year classes are present for many sunfish species including bluegill, redear sunfish, and largemouth bass. This indicates that the community is healthy overall. Growth rates for fish present in Kreighbaum and Millpond Lakes appear to be somewhat slower than fish found in Cook and Holem Lakes. However, both fish communities are in good condition. Additionally, common carp and gizzard shad were noticeably absent from the two IDNR surveys. To maintain the lakes' fishery, efforts should be made to preclude either of these two fish species from being introduced.

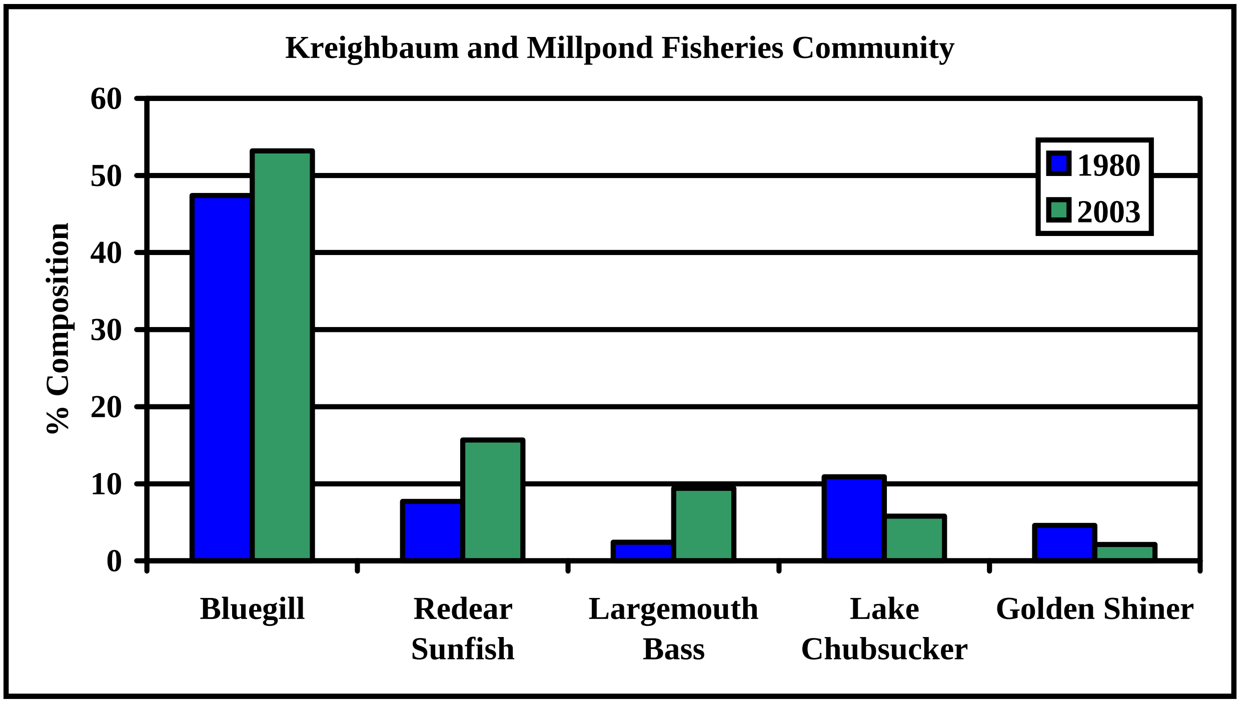

Figure 52. Percent community composition for Kreighbaum Millpond Lakes.
Source: Rowe, 1981; Price, 2004.

6.0 MODELING

6.1 Water Budget

Water budgets are useful for lakes because they help identify significant water sources that may be important in the management plan. For example, one inlet stream may contribute more water and nutrients than another and this could help direct management efforts. The total amount of water flowing into and out of a lake is used to determine the ***hydraulic residence time*** and the ***hydraulic flushing rate***. The hydraulic residence time is the average time required to completely replace the lakes current volume of water with and equal volume of new water (Holdren et al., 2001). The hydraulic flushing rate is the inverse or the number of times the complete volume of water in the lake is exchanged per year. The rate at which water flows through a lake affects turbulence and settling rates of sediments and nutrients. It also helps determine whether the lake's water quality is influenced more by water flowing into the lake or by water already in the lake.

Water enters the Four Lakes from the following sources:

- direct precipitation to each lake
- sheet runoff from land immediately adjacent to the lake
- groundwater
- water from upstream lakes

Water leaves the lakes from:

- discharge from Millpond Lake via the Harry Cool Ditch outlet
- evaporation from each lake
- groundwater

There are no discharge gauges in the watershed to measure water inputs and the limited scope of this study did not allow for the quantitative determination of annual water inputs or outputs. Therefore, the water budgets for Cook, Holem, Kreighbaum, and Millpond Lakes were estimated from other records.

- Direct precipitation to the lakes was calculated from mean annual precipitation falling directly on the lakes' surface.
- Runoff from the lakes' watershed was estimated by applying runoff coefficients. A runoff coefficient refers to the percentage of precipitation that occurs as surface runoff, as opposed to that which soaks into the ground. Runoff coefficients may be estimated by comparing discharge from a nearby gauged watershed of similar land and topographic features, to the total amount of precipitation falling on that watershed. The nearest gauged watershed is a U.S.G.S. gauging station on the Yellow River at Plymouth, Indiana (Morlock et al., 2004). The 55-year (1949–2003) mean annual discharge from this watershed is 269 cfs (cubic feet per second). With a mean annual precipitation for Marshall County of 36.78 inches (Smallwood, 1980), this means that on average, 34% of the rainfall falling on this watershed runs off the land surface.
- No groundwater records exist for the lakes so it was assumed that groundwater inputs equal outputs or groundwater effects are insignificant compared to surface water impacts. However, since there is little elevation change among the surfaces of the Four Lakes, and since the water table is at or very near the surface through much of the watershed, we expect there to be significant surface and subsurface water movement between the lakes. We simply cannot measure this water movement given the constraints of this study.
- Evaporation losses were estimated by applying evaporation rate data to the lake. Evaporation rates are determined at six sites around Indiana by the National Oceanic and Atmospheric Administration (NOAA). The nearest site to the Four Lakes watershed is located in Valparaiso, Indiana. Annual evaporation from a 'standard pan' at the Valparaiso site averages 28.05 inches per year. Because evaporation from the standard pan overestimates evaporation from a lake by about 30%, the evaporation rate was corrected by this percentage, yielding an estimated evaporation rate from the lakes' surface of 19.95 inches per year. Multiplying this rate times the surface area of each lake yields an estimated volume of evaporative water loss from the lakes.

Table 50 shows the hydraulic residence time, which results from dividing the amount of water leaving each lake by the individual lake's volume. Figure 53 diagrams the water inputs and outputs for each of the Four Lakes. (Appendix F contains the detailed water budget spreadsheet, based on assumptions discussed above, for each of the study lakes.) The hydraulic residence times range from only 62 days (0.17 years) for Millpond Lake to nearly 504 days (1.38 years) for Holem Lake. This means that water enters Millpond Lake and stays an average of only 62 days before it leaves. Likewise, water enters Kreighbaum Lake and stays 288 days (0.79 years) before being completed flushed to Millpond Lake. The hydraulic flushing rates for Cook, Kreighbaum, and Millpond Lakes are relatively rapid for lakes in this part of the country. In a study of 95 northern temperate lakes in the United States, the mean hydraulic residence time was 2.12 years (Reckhow and Simpson, 1980). Lakes in the Four Lakes watershed possess ratios that are higher than most glacial lakes; however, they are much lower than typical ratios for reservoirs where watershed area to reservoir surface area typically ranges between 100:1 and 300:1 (Vant, 1987).

Table 50. Water budget summaries for Cook, Holem, Kreighbaum, and Millpond Lakes

Lake	Volume (V, in acre-ft)	Discharge (Q) (in acre-feet per yr)	Residence Time (V/Q) (in years)
Cook	1647	1989	0.83
Holem	387	280	1.38
Kreighbaum	425	536	0.79
Millpond	578	3390	0.17

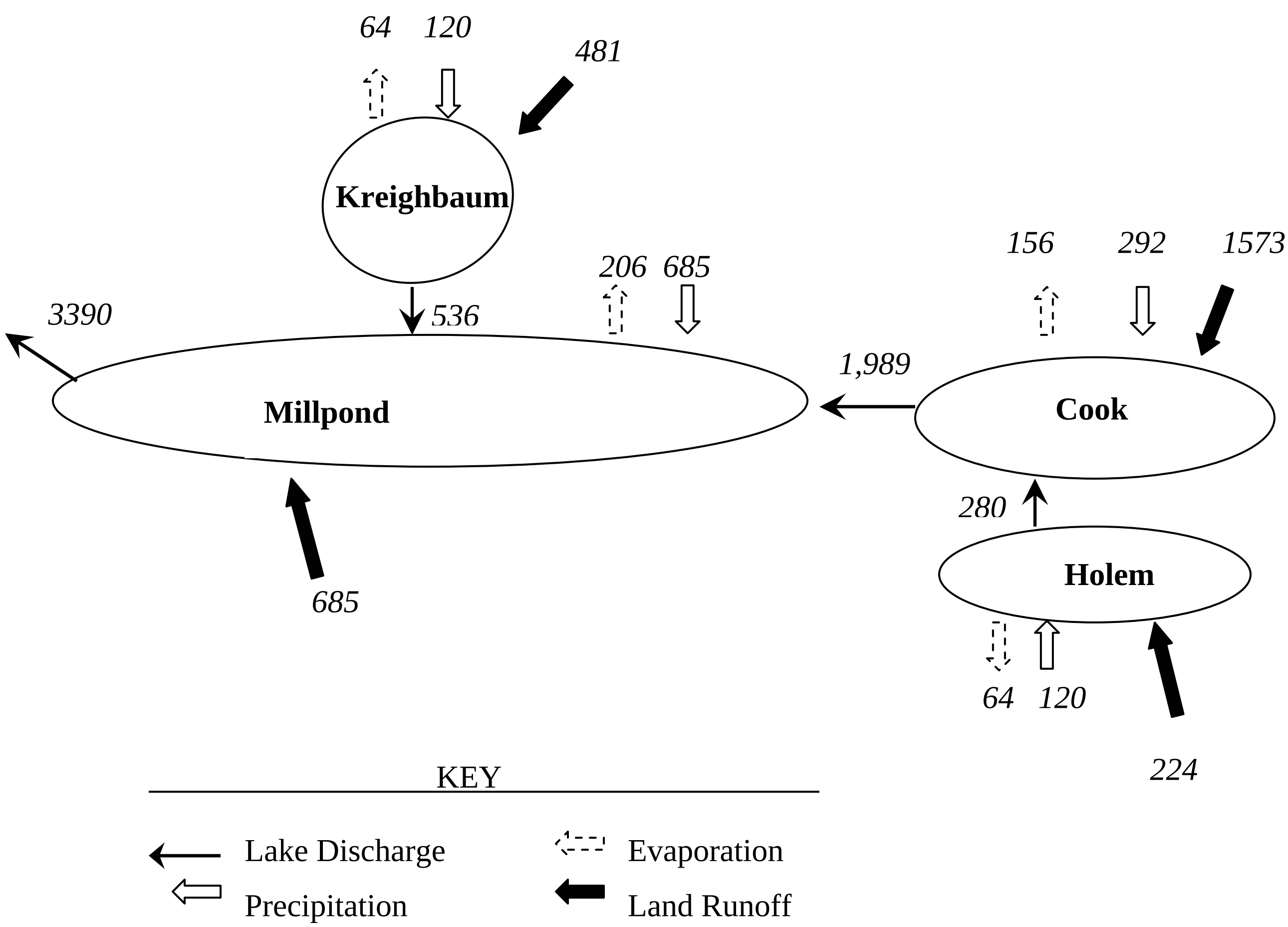

Figure 53. Water budget flow chart for the Four Lakes watershed. Note: All units are acre-feet.

As previously noted, residence time estimates can be used to help guide management of the lakes. In general, lakes possessing long residence times often benefit from in-lake management techniques, while lakes possessing short residence times benefit from watershed management techniques. (See below for a word of caution on this general rule.) In lakes with short residence time, such as such as Millpond Lake, water is continuously moving through the lake. Thus, the lakes with short residence times would have good water quality if the water entering these lakes is clean. Conversely, water stays in lakes with long residence time for a longer period of time. As a consequence, internal processes, such as internal phosphorus release from the lake's sediments, can have a larger impact on water quality than the condition of the incoming surface water.

The interconnectedness of the lakes clearly complicates the general rule described above. Cook Lake may have a relatively short hydraulic residence time, but much of the water coming into Cook Lake comes from lakes located upstream of it. Myers and Lawrence Lakes contribute water to Cook Lake. As a consequence, internal processes that occur in Myers and Lawrence Lakes affect the water quality of Cook Lake. These factors must be considered when deciding on management strategies.

6.2 Phosphorus Model

Since phosphorus is typically the limiting nutrient in lakes and because it is the easier of the two main nutrients (phosphorus and nitrogen) required for plant and algal growth to control (Lee and Jones-Lee, 1998), a phosphorus model was used to estimate the dynamics of this important nutrient. With its role as the limiting nutrient, phosphorus should be the target of management activities to lower the biological productivity of these lakes.

The limited scope of this study did not allow for the outright determination of phosphorus inputs and outputs. Therefore, a standard phosphorus model was utilized to estimate the phosphorus budget. Reckhow et al. (1979) compiled phosphorus loss rates from various land use activities as determined by a number of different studies. They calculated these phosphorus loss rates to calculate phosphorus export coefficients for various land uses. Phosphorus export coefficients are expressed as kilograms of phosphorus lost per hectare of land per year. Table 51 shows the phosphorus export coefficients developed by Reckhow and Simpson (1980).

Table 51. Phosphorus export coefficients (units are kilograms/hectare except the septic category, which are kg/capita-yr).

Estimate Range	Agriculture	Forest	Precipitation	Urban	Septic
High	3.0	0.45	0.6	5.0	1.8
Mid	0.40-1.70	0.15-0.30	0.20-0.50	0.80-3.0	0.4-0.9
Low	0.10	0.2	0.15	0.50	0.3

Source: Reckhow and Simpson, 1980.

To obtain an annual estimate of the phosphorus exported to the Four Lakes from the lakes' watershed(s), the export coefficient for a particular land use was multiplied by the area of land in that land use category. Mid-range estimates of phosphorus export coefficient values for all watershed land uses (Table 51) were used in this calculation.

Direct phosphorus input via precipitation to the lakes was estimated by multiplying mean annual precipitation in Marshall County (0.9 m/yr) times the surface area of each lake times a typical phosphorus concentration in Indiana precipitation (0.03 mg/L). For septic system inputs, the number of permanent homes on each lake was multiplied times an average of 3 residents per home to calculate per capita years. Using a mid-range phosphorus export of 0.5 kg/capita-yr and a soil retention coefficient of 0.75 (this assumes that the drain field retains 75% of the phosphorus applied to it), phosphorus export from septic systems was calculated. For temporary residences, an average of 6 months per year was used to calculate septic system inputs. Likewise, for seasonal residences, 3 months per year was utilized.

Because these lakes are part of a chain and drain into each other, the amount of phosphorus loading entering Cook Lake from the Holem Lake outlet and that entering Millpond from the Kreighbaum and Cook Lake outlets were also estimated. These were calculated by multiplying the lake discharge calculated during modeling of the water budget by the mean whole lake total phosphorus concentration.

Adding the phosphorus export loads from the watershed, septic systems, and precipitation yielded an estimated 527 kg of phosphorus loading to Cook Lake, annually (Table 52). According to the model, the greatest source of watershed phosphorus loading to Cook Lake is from row crop agriculture, accounting for over 72% of total watershed loading (Table 53). Row crops were estimated to be the greatest watershed source of phosphorus loading to Holem (71%), Kreighbaum (81%), and Millpond (62%) Lakes, as well. Holem and Millpond Lakes also received substantial estimated total phosphorus loading from urban areas, including both residential and commercial land uses. Total phosphorus loading to Millpond from the Kreighbaum and Cook Lake outlets (463.3 kg/yr) accounted for more of Millpond Lake's phosphorus load than was estimated from direct watershed runoff.

Table 52. Results of phosphorus export modeling.

Watershed	Total P Loading (kg/yr) from External Sources	Total P Loading (kg/yr) from Lake Discharge
Cook	526.9[1]	30.4[2]
Holem	93.2	-
Kreighbaum	196.9	-
Millpond	160.6[1]	463.3[3]

[1]Not including phosphorus discharge from upstream lakes
[2]from Holem Lake
[3]from Cook and Kreighbaum lakes

Table 53. Results of watershed portion of phosphorus export modeling.

Watershed	Total P Loading (kg/yr) from Watershed Sources	% Loading from Row Crops	% Loading from Forest	% Loading from Urban[1]
Cook	484.6	72.4%	4.3%	9.6%
Holem	69.1	70.8%	5.8%	20.2%
Kreighbaum	178.9	80.6%	2.9%	5.6%
Millpond	164.1	62.3%	7.9%	15.5%

[1]surface runoff only, not including septic system loading

The relationships among the primary parameters that affect a lake's phosphorus concentration were examined employing the widely used Vollenweider (1975) phosphorus loading model.

Vollenweider's empirical model says that the concentration of phosphorus ([P]) in a lake is proportional to the areal phosphorus loading (L, in g/m^2 lake area per year), and inversely proportional to the product of mean depth ($\bar{z}$) and hydraulic flushing rate (ρ) plus a constant (10):

$$[P] = \frac{L}{10 + \bar{z}\rho}$$

During the August 11, 2004 sampling of Holem Lake, the mean volume weighted phosphorus concentration in the lake was 0.088 mg/L. It is useful to determine how much of the phosphorus loading from all sources is required to yield a mean phosphorus concentration of 0.088 mg/L in Holem Lake. Plugging this mean concentration, along with the mean depth and flushing rate, into Vollenweider's phosphorus loading model and solving for L, yields an estimated areal phosphorus loading rate (mass of phosphorus per unit area of lake) of 1.076 g/m^2-yr. This means that in order to get a mean phosphorus concentration of 0.088 mg/L in Holem Lake, a total of 1.076 grams of phosphorus must be delivered to each square meter of lake surface area per year.

Total phosphorus loading (L_T) is composed of external phosphorus loading (L_E) from outside the lake (watershed, septics, and precipitation) and internal phosphorus loading (L_I). Since L_T = 1.076 g/m^2-yr and L_E = 0.590 g/m^2-yr (estimated from the watershed loading in Table 52), then internal phosphorus loading (L_I) equals 0.485 g/m^2-yr. Thus, internal loading accounts for about 45% of total phosphorus loading to Holem Lake.

It is important to check this conclusion that internal phosphorus loading accounts for 45% of total phosphorus loading to Holem Lake. There is evidence in Holem Lake that soluble phosphorus is being released form the sediments during periods of anoxia. For example, the concentration of soluble phosphorus in Holem Lake's hypolimnion (0.199 mg/L) on August 11, 2004 was 4.2 times higher than concentrations in the epilimnion (0.047 mg/L). Additionally, a large portion of the total phosphorus present in Holem Lake consisted of soluble reactive phosphorus. The source of this hypolimnetic phosphorus is primarily internal loading in most lakes. This internal loading can be a major source of phosphorus in many productive lakes. The modeled estimate of 45% of annual phosphorus loading originating from internal sources seems reasonable given the large difference between summertime epilimnetic and hypolimnetic phosphorus concentrations.

The Vollenweider phosphorus loading model was also used with data from Cook, Kreighbaum, and Millpond Lakes. Results for all four lakes are included in Table 54. (Appendix G contains detailed phosphorus modeling spreadsheets for each lake.) Note that total loading to Cook Lake includes phosphorus discharge from the Holem Lake outlet and that total loading to Millpond Lake includes phosphorus discharge from the Cook Lake and Kreighbaum Lake outlets. For purposes of modeling, it was assumed that all watershed runoff from the Myers Lake watershed reaches Cook Lake as overland flow; that all phosphorus exported from Holem Lake reaches Cook Lake; and that all phosphorus exported from Cook Lake and Kreighbaum Lakes reach Millpond Lake. Given the fact that water does not always flow from Myers Lake to Cook Lake and that the culvert connecting Myers Lake to Cook Lake was approximately 2 feet (1.8 m) above the water level at Myers Lake on August 11, 2004, it is unlikely that all of the phosphorus from the Myers Lake watershed reaches Cook Lake. Including the Myers Lake watershed loading in the phosphorus model could result in an overestimate of Cook Lake's areal and internal loading. Since Cook Lake's phosphorus loading is utilized to calculate Millpond Lake's phosphorus loading, this overestimate could create a domino effect resulting in an overestimate of Millpond Lake's phosphorus loading. The limited budget of this LARE study does not allow for the monitoring needed to calculate what portion of phosphorus flows from the Myers Lake watershed through the connecting culvert, the estimates presented in this model represent our best professional judgment.

Table 54. Areal phosphorus loading rates determined from models.

Lake	Total Areal P Loading (g/m^2 – yr)[1]	External Areal P Loading (g/m^2 – yr)[2]	Internal Areal P Loading (g/m^2 – yr)
Cook[3]	2.85	1.64	1.21
Holem	1.08	0.59	0.49
Kreighbaum	1.15	1.25	-0.10
Millpond[4]	0.89	1.22	-0.33

[1]estimated from Vollenweider's lake response model
[2]estimated from Reckhow's phosphorus export model and precipitation estimates
[3]includes phosphorus discharge from Holem Lake
[4]includes phosphorus discharge from Cook and Kreighbaum Lakes

Vollenweider's model estimates a *negative* rate of internal phosphorus loading for both Kreighbaum and Millpond Lakes. This negative loading rate could result from a number of reasons. Vollenweider's model was developed using deeper lakes than the Four Lakes <u>and</u> his lake's possessed longer residence times than those estimated for the Four Lakes. Additionally, the current estimate of residence time for the Four Lakes negates the impact of groundwater. Given the predominance of hydric soils surrounding the Four Lakes, it is likely that groundwater interactions account for some portion of water flow into and out of these lakes. The assumption that groundwater inputs are equal to groundwater outputs or that groundwater interactions were insignificant compared with surface water interactions may not hold true for the Four Lakes. The calculation of groundwater interactions at the Four Lakes is simply outside the scope of the current study; therefore, this assumption is necessary to estimate the lakes' residence times. However, if groundwater interactions were included, the residence times calculated could be different than those estimated in the *Water Budget Section* of this report resulting in different areal loading rates.

Ultimately, the negative loading rate estimated using Vollenweider's model means that the quantity of phosphorus entering the lakes from their watershed on an annual basis is not present in the lakes' water column. The model accounts for this excess phosphorus by allocating it to the lake sediment; however, it is more likely that the phosphorus is utilized by the rooted plants instead, resulting in additional plant biomass. Kreighbaum Lake, with its emergent wetland located south of the main body of open water, and Millpond Lake, which possesses greater than 90% plant cover, have extremely dense rooted plant communities which compete with algae for available nutrients and light. Vollenweider's phosphorus model simply cannot account for rooted plant populations of this magnitude.

The significance of areal phosphorus loading rates is better illustrated in Figure 54 in which areal phosphorus loading is plotted against the product of mean depth times flushing rate. Overlain on this graph is a line, based on Vollenweider's model, which represents an acceptable loading rate that yields a phosphorus concentration in lake water of 30 μg/L (0.03 mg/L). The areal phosphorus loading rate for each lake is above the acceptable line.

This figure can also be used to evaluate management needs. For example, areal phosphorus loading to Cook Lake would have to be reduced from 2.854 g/m^2-yr to 0.512 g/m^2-yr (the downward vertical intercept with the line) to yield a mean lake water concentration of 0.030 mg/L. This represents a reduction in areal phosphorus loading of 2.342 g/m^2-yr to the lake (82%), which is equivalent to a total phosphorus mass loading reduction of 796 kg P/yr. Similar calculations are shown in Table 55 for the other lakes.

Table 55. Phosphorus reduction required to achieve acceptable phosphorus loading rate and a mean lake concentration of 0.03 mg/L.

Lake	Current Total Areal P Loading (g/m^2-yr)	Acceptable Areal P Loading (g/m^2-yr)	Reduction Needed (kg P/yr and %)
Cook	2.854	0.512	2.342 (82%)
Holem	1.076	0.366	0.710 (66%)
Kreighbaum	1.148	0.426	0.722 (63%)
Millpond	0.892	0.510	0.382 (43%)

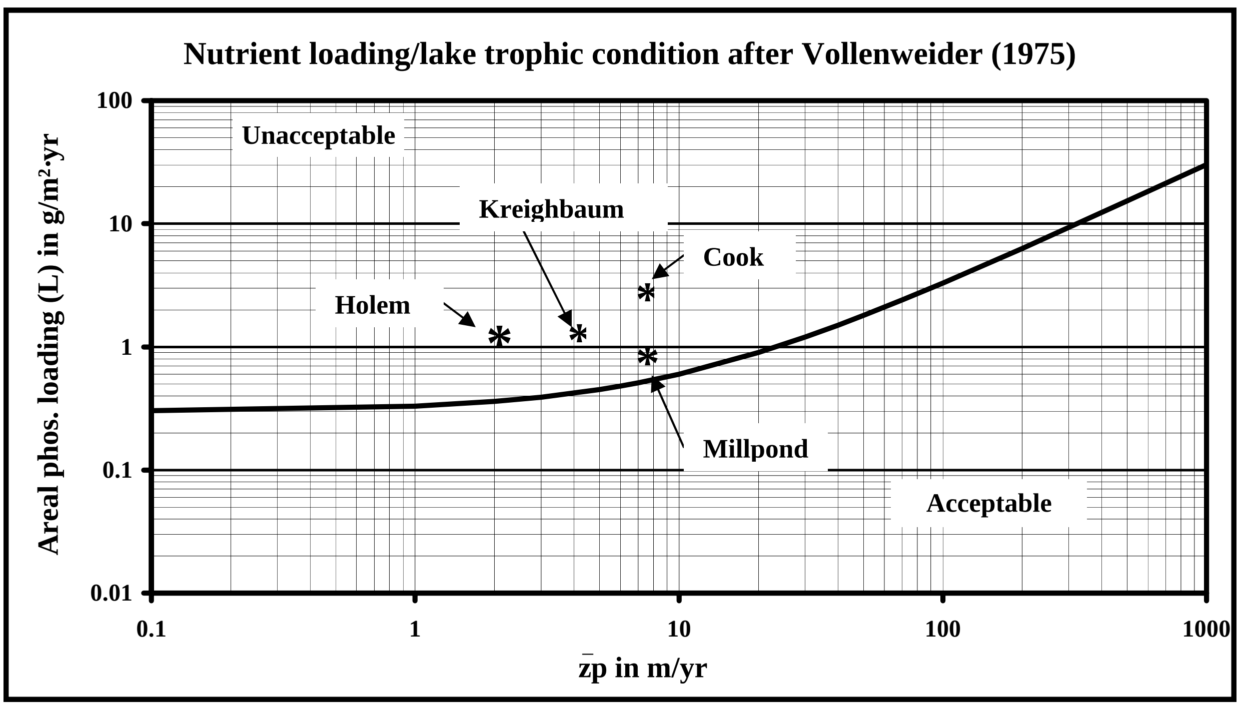

Figure 54. Phosphorus loadings to Cook, Holem, Kreighbaum, and Millpond Lakes compared to acceptable loadings determined from Vollenweider's model. The dark line represents the upper limit for acceptable loading.

7.0 MANAGEMENT

Restoration or even minor improvement in a lake's health often requires the implementation of both in-lake and watershed management techniques. Data collected from Cook, Holem, Kreighbaum, and Millpond Lakes and their watershed suggests that this will be the case with the study lakes as well. For example, high hypolimnetic soluble reactive phosphorus concentrations in two of the study lakes, Cook and Kreighbaum Lakes, suggest that phosphorus is being released from the sediments during periods of anoxia. The study lakes may benefit from an alum treatment, a common in-lake treatment, to address the high hypolimnetic phosphorus concentrations. Similarly, high hypolimnetic ammonia concentrations in each of the lakes suggest in-lake treatment such as removal of the organic matter may be warranted.

Before any management actions can be taken, a comprehensive look at the current and best uses of the lakes must be conducted. Critical to this evaluation is a consideration of the 'nature' of the lakes themselves. Based on the results of the water quality, plant community, and in-lake sampling and field inspections documented in this report, the following generalizations characterize the Four Lakes:

1. The lakes are shallow (< 30 feet or 9.1 m in depth) or possess extensive shallow areas.
2. Rooted aquatic plants cover much of the shallow areas in the lakes.
3. The lakes possess elevated nutrient concentrations, especially phosphorus.
4. Kreighbaum and Millpond Lakes fall in the mesotrophic category when scored using the Indiana Trophic State Index, while Cook and Holem Lakes are in the eutrophic category using the Indiana Trophic State Index. However, all Cook, Holem, and Kreighbaum Lakes fall in the hypereutrophic category when scored using Carlson's Total Phosphorus Trophic State Index, while Millpond Lake is eutrophic.
5. The lakes lack oxygen in their deeper waters (hypolimnia).
6. Many of the lakes internally release phosphorus from their sediments.
7. Portions of the lakes possess inadequate buffers.
8. Cook, Kreighbaum, and Millpond Lakes exhibit moderate water clarity; Holem Lake exhibits poor water transparency.

Some of the characteristics listed above simply describe the nature of the lakes as they have always been. For example, these lakes have always been shallow in nature. In fact given the origin of northern Indiana lakes, few northern Indiana lakes possess great depths (> 100 feet or 31.4 m). Because the observed depth is natural, watershed residents should not take lake management steps to increase the depths of the Four Lakes unless increasing the depth achieves other management goals as well.

Some characteristics of the Four Lakes are of concern. Additionally, these conditions have the potential to limit the uses of the lakes. For example, many of the visitors to the lakes enjoy the quiet beauty of the lakes. Currently, Kreighbaum and Millpond Lakes possess average water clarity and low algal densities. However, the high nutrient concentrations in the lakes have the potential to increase algae populations. Few people find algae blooms aesthetically attractive. Similarly, many people enjoy fishing on the lakes. Oxygen depletion in the lakes' bottom waters limits the available habitat for fish. An increase in the lakes' anoxia could impair fishing opportunities on the lakes. Lake and watershed residents should take steps to manage those characteristics of the lakes that have the potential to impair desired uses of the lakes.

Furthermore, each of the Four Lakes possess small shoreline development ratios. This is especially true for Holem and Kreighbaum Lakes, which are both extremely small compared with the amount of shoreline-water interface present at each lake. This suggests that individuals residing along the shoreline of the Four Lakes, especially Holem and Kreighbaum Lakes, possess a greater ability to improve water quality within their lake than most shoreline residents in Indiana.

Because residents use the lakes for different activities, there will necessarily be some conflict regarding how the lakes should be managed. For instance, anglers might prefer for the lakes to be more productive than those who enjoy the aesthetic value of the lakes. Fisheries researchers report increasing sport fish production with increasing levels of total phosphorus, including levels as high as 0.1 mg/L (Schramm, 2002). This level of total phosphorus is three times higher than the level at which nuisance algae blooms could occur. Similarly, swimmers and boaters might disagree with anglers on the amount of rooted plant growth that is acceptable in the lakes. Additionally users' desires must be balanced with the ecological capacity of the lakes to sustainably provide the desired uses.

Based on work completed during this study, there is evidence that the lakes' watershed exerts a larger influence on the health of the study lakes and this influence is likely greater in magnitude than the influence of in-lake processes on the health of the lakes. This is especially true in Cook, Kreighbaum, and Millpond Lakes which all possess relatively short hydraulic residence times. Holem Lake's residence time is longer (26 months). The lakes' short residence times mean that water from the watershed is continually replacing the water in each lake. Thus, it is more cost-effective to improve the quality of water entering each lake, rather than working on the water quality once the water is in the lake.

Collectively, the data indicate that management efforts should focus on controlling external sources of pollutants before addressing internal sources of pollutants. In-lake management will likely need to be explored in the future once external sources of pollutants are controlled. The following sections describe many of the management techniques most applicable to the Four Lakes. (Appendix H provides information on potential funding sources available to help fund the implementation of management projects.) For the sake of clarity, the techniques are separated into two categories: watershed management techniques and in-lake management techniques. Although aquatic plant management is an important component of in-lake management, the aquatic plant management discussion is contained in the *Macrophyte Inventory Section* and will not be repeated here. Readers should refer to this section for more information of management of rooted plants in the Four Lakes.

7.1 Watershed Management

7.1.1 Individual Property Management

Individual property owners can take several actions to improve the water quality in the Four Lakes. First, watershed property owners should reduce or eliminate the use of fertilizers and pesticides. These lawn and landscape-care products are a source of nutrients and toxins to the lakes and streams. Landowners typically apply more fertilizer to lawns and landscaped areas than necessary to achieve the desired results. Plants can only utilize a given amount of nutrients. Nutrients not absorbed by the plants or soil can run into the lakes either directly from those residents' lawns along the lakes' shoreline or indirectly via storm drains or ravines. This simply fertilizes the rooted plants and algae in the lakes and impairs the biotic communities in the lakes. At the very minimum, landowners should follow dosing recommendations on product labels and avoid fertilizer/pesticide use within 10 feet (3.1 m) of hard surfaces such as roads, driveways, and sidewalks and within 10 to 15 feet (3.1 to 4.6 m) of the water's edge. Where possible, natural landscapes should be maintained to eliminate the need for pesticides and fertilizers. Alternatively, landowners should consider replacing high maintenance turf grasses with grasses that have lower maintenance requirements such as some fescue (*Festuca*) species.

If a landowner considers fertilizer use necessary, the landowner should apply phosphorus-free fertilizers. (Slow-release, organic, phosphorus-free fertilizers are recommended.) Several researchers have found residential lawns to be critical sources of phosphorus (Bannerman et al., 1992; Steury et al., 1997). Most fertilizers contain both nitrogen and phosphorus. However, the soil usually contains enough natural phosphorus to allow for plant growth. As a consequence, fertilizers with only nitrogen work as well as those with both nutrients. The excess phosphorus that cannot be absorbed by the grass or plants can enter the lakes, again either directly or via storm drains. Landowners can have their soil tested to ensure that their property does indeed have sufficient phosphorus and that no additional phosphorus needs to be added. The Purdue University Extension or a local supplier can usually provide information on soil testing.

Another alternative to reducing fertilizer use or using only phosphorus free fertilizers is to use the lake water to hydrate and fertilize the lawn. The lake water contains both phosphorus and nitrogen and consequently may serve as a suitable fertilizer for lawns adjacent to the lake. This concept has been utilized at other eutrophic lakes with residential land use bordering the lake. By using lake water to fertilize the adjacent lawns, no new nutrients are added to the lake and some are potentially removed.

Shoreline landowners should also avoid depositing lawn waste such as leaves and grass clippings in the lakes as this adds to the nutrient base in these aquatic systems. Pet and other animal waste that enters the lakes also contributes nutrients and pathogens to the waterbodies. All of these substances require oxygen to decompose. This increases the demand on the already oxygen-strained lakes. Yard, pet, and animal waste should be placed in residents' solid waste containers to be taken to the landfill, rather than leaving the waste on the lawn or piers to decompose.

Each lake property owner should investigate local drains, roads, parking areas, driveways, and rooftops. Resident surveys conducted on other northern Indiana lakes have indicated that many lakeside houses have local drains of some sort on their properties (Figures 55 and 56). These drains contribute to sediment and nutrient loading and thermal pollution to the lakes. Where possible, alternatives to piping the water directly to the lake should be considered. Alternatives include French drains (gravel filled trenches), wetland filters, catch basins, and native plant overland swales.

Figure 55. Residential storm drain located during the Four Lakes watershed tour.

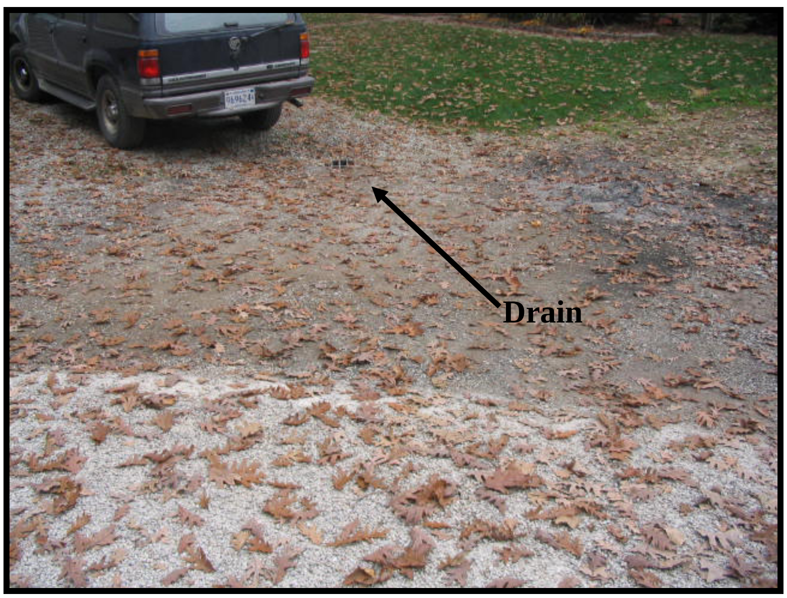

Figure 56. Residential storm drain located during the Four Lakes watershed tour.

Residents should disconnect stormwater drainage paths and consider the installation of vegetative filters, rain gardens, gravel infiltration trenches, or other drainage structures that promote infiltration and pollutant treatment over stormwater conveyance. While connecting downspouts with street drains keeps lawns well drained, these direct drainages prevent any pollutant treatment or infiltration (and therefore loss of stormwater volume) that the lawn or natural landscape may provide. Disconnecting these individual stormwater conduits should especially be encouraged in the areas of the watershed where soils are best suited for this.

Lastly, individuals should take steps to prevent unnecessary pollutant release from their property. With regard to car maintenance, property owners should clean any automotive fluid (oil, antifreeze, etcetera) spills immediately. Driveways and street fronts should be kept clean and free of sediment. Regular hardscape cleaning would help reduce sediment and sediment-attached nutrient loading to the waterbodies in the watershed. Street cleaning would also reduce the watershed loading of heavy metals and other toxicants associated with automobile use. Residents should avoid sweeping driveway silt and debris into storm drains. Rather, any sediment or debris collected during cleaning should be deposited in a solid waste container.

7.1.2 Shoreline Buffers

Healthy buffers around any waterbody are important for protecting water quality in a watershed. Vegetative buffers slow overland flow and reduce flow volume by increasing infiltration of runoff. This supports the ecosystem's natural hydrological regime that existed prior to development around the lakes. Buffers also help filter sediments, nutrients, pesticides, pathogens, and other pollutants from runoff, preventing these pollutants from reaching the lakes. Buffers can reduce up to 80% of the sediment, 50% of the phosphorus, and 60% of the pathogens in runoff (Conservation Technology Information Center, 2000). Buffers immediately adjacent to the lake also protect the lake from wave action limiting erosion, release oxygen to the water column for use by aquatic biota, and provide food, cover, and spawning/nesting habitat for a variety of fish, waterfowl, insects, mammals, and amphibians. Additionally, large, tall buffers along lakeshores can discourage nuisance waterfowl, such as Canada geese, from taking up residence in the area. Canada geese prefer maintained lawns because they are easy to access from the water and any predators are clearly visible in lawn areas. Lawns also provide a vast food resource for the geese. Native vegetation is higher in profile than maintained lawns and has the potential to hide predators, increasing the risk for the geese. Some native vegetation, such as blue iris and cattails, is stiff, making it difficult for geese to access the lawn behind the vegetation.

Some of the more tangible benefits of a naturally vegetated lakeshore are included in the following list:

- Healthy and diverse shoreline vegetation provide good habitat for fish, insects, amphibians, and other shoreline animals.
- Good habitat improves the health and diversity of shoreline and upland birds and wildlife.
- Shoreline trees shade the water improving fish habitat and fishing success.
- Natural shoreline is attractive as seen from the water and the land.
- Natural vegetation screens structures and makes them less intrusive.
- Natural vegetation protects the lake bed and shoreline from the erosive forces associated with waves.
- Native vegetation provides color, texture, and variety to landscaping.
- Precipitation is slowed and redirected through trees, shrubs, and ground level vegetation on the shoreline so that only about 10% of runoff reaches the lake.
- Pollutants, including sediments, nutrients, toxins, from the land are prevented from entering the water by dense, natural shoreline vegetation.
- Water is filtered before it enters the ground resulting in cleaner drinking water.

Like many of the lakes in northern Indiana (and much of the Midwest), several portions of the Four Lakes suffer from inadequate buffers. Despite the importance of shoreline buffers, many residents remove any vegetation from their shoreline property. Removal of this vegetation results in a loss of many of the shoreline ecosystem functions listed above. The consequence is often visible in the lake water quality or clarity.

Given the relatively high nutrient concentrations observed in the Four Lakes, the installation and maintenance of buffer zones around these lakes should be a priority. A number of individual residences would strongly benefit from the installation of a shoreline buffer. Figures 57 through 60 detail representative locations along the Four Lakes' shoreline. As the photos below (Figures 57 through 59) indicate, the manicured turf grass of these Cook, Kreighbaum, and Millpond Lakes properties extends to the water's edge with no emergent buffer between the lakes and the yard. Any fertilizers or pesticides applied to the lawn can simply wash right into the Four Lakes, degrading the lakes' water quality. In addition to nutrient and pesticide input, leaves and grass clippings also wash into the lakes. These organic materials increase turbidity and utilize oxygen in the water column as they decompose. The water quality assessment for the Four Lakes showed that the lakes possess large anoxic zones. The lack of buffers around the lakes contributes to this impairment. The easy access to a food source also makes these areas attractive to geese. Geese, in turn, contribute to the nutrient and pathogen loads to the lake. Because Cook and Kreighbaum Lakes lie upstream of Millpond Lake, poor water quality in these lakes can impact the other lakes in the chain, specifically Millpond Lake. Conversely, Figure 60 details portions of Holem Lake's steep shoreline where the vegetation provides a buffer from the lake's immediate watershed activities.

Figure 57. Cook Lake shoreline sloping to the lake without any vegetated buffer. Note the general lack of shoreline and littoral vegetation that provides important functions and ecological habitat.

Figure 58. Kreighbaum Lake properties possessing narrow or absent shoreline buffers.

Figure 59. Portions of Millpond Lake where shoreline buffers are absent.

Figure 60. Steep, well-vegetated shoreline with emergent vegetation in littoral zone present along Holem Lake's shoreline.

Individual lakeshore property owners can create their own shoreline buffers on their properties. Potential plant species to utilize in shoreline planting and their benefits have been well documented (Henderson et al., 1998; Mississippi Headwateres Board, no date). Some potential shoreline buffer species are listed in Table 56. In those areas that do not have seawalls, rushes (*Juncus* spp.), sedges (*Carex* spp.), pickerel weed (*Pontederia cordata*), arrowhead (*Sagittaria latifolia*), and blue-flag iris (*Iris viginica*) offer an aesthetically attractive, low profile community in wet areas. Behind existing seawalls, a variety of upland forbs and grasses that do not have the same fertilizer or pesticide maintenance requirements as turf grass may be planted instead of turf grass. Plantings can even occur in front of existing seawalls. Bulrushes (*Scirpus* spp.) and taller emergents are recommended for this. (All sites should be inspected prior to planting to ensure the appropriate species are planted for existing site conditions.) While not providing all the functions of a native shoreline, plantings in front of seawalls provide fish and invertebrate habitat. As noted above, the restoration of native shoreline or the planting of emergents in front of seawalls also discourages Canada geese. Partial or full restoration of the native shoreline community on individual private properties also provides erosion control and runoff filtration prior to surface water entering the lakes.

Table 56. Potential shoreline buffer species.

Common Name	Botanical Name	Approximate Location*
Arrow Arum	*Peltandra virginica*	Shallow water/water's edge
Big Blue Stem	*Andropogon gerardii*	Varies/broad range
Black-Eyed Susan	*Rudbeckia hirta*	Drier soils
Blue Flag Iris	*Iris virginica shrevei*	Shallow water/water's edge
Blue Joint Grass	*Calamagrostis canadensis*	Wet to mesic soils
Bottle Gentian	*Gentiana andrewsii*	Mesic to dry soils
Butterfly Milkweed	*Asclepias tuberosa*	Mesic to dry soils
Chairmakers rush	*Scirpus pungens*	Shallow water/water's edge
Common Bur Reed	*Sparganium eurycarpum*	Shallow water/water's edge
Compass Plant	*Silphium laciniatum*	Varies/broad range

Common Name	Botanical Name	Approximate Location*
Cream Wild Indigo	*Baptisia leucophaea*	Mesic to dry soils
Culver's Root	*Veronicastrum virginianum*	Varies/broad range
Cup Plant	*Silphium perfoliatum*	Wet to mesic soils
Early Goldenrod	*Solidago juncea*	Wet to mesic soils
False Dragonhead	*Physostegia virginiana*	Wet to mesic soils
Goats Rue	*Tephrosia virginiana*	Varies/broad range
Golden Alexanders	*Zizia aurea*	Wet to mesic soils
Great Blue Lobelia	*Lobelia siphilitica*	Wet soils
Halberd-leaved Rose Mallow	*Hibiscus laevis*	Shallow water/water's edge
Hard-stemmed Bulrush	*Scirpus acutus*	Shallow water/water's edge
Heart-Leaved Meadow Parsnip	*Zizia aptera*	Mesic to dry soils
Heath Aster	*Aster ericoides*	Wet to mesic soils
Illinois Sensitive Plant	*Desmanthus illinoensis*	Mesic to dry soils
Illinois Tick Trefoil	*Desmodium illinoiense*	Varies/broad range
Indian Grass	*Sorghastrum nutans*	Varies/broad range
Ironweed	*Vernonia altissima*	Wet to mesic soils
Little Blue Stem	*Andropogon scoparius*	Varies/broad range
Marsh Blazing Star	*Liatris spicata*	Wet to mesic soils
New England Aster	*Aster novae-angliae*	Wet to mesic soils
New Jersey Tea	*Ceanothus americanus*	Varies/broad range
Old-Field Goldenrod	*Solidago nemoralis*	Mesic to dry soils
Partridge Pea	*Cassia fasciculata*	Varies/broad range
Pickerel Weed	*Pontederia cordata*	Shallow water/water's edge
Prairie Bergamot	*Monarda fistulosa*	Varies/broad range
Prairie Cinquefoil	*Potentilla arguta*	Mesic to dry soils
Prairie Cord Grass	*Spartina pectinata*	Wet to mesic soils
Prairie Coreopsis	*Coreopsis palmata*	Mesic to dry soils
Prairie Dock	*Silphium terebinthinaceum*	Varies/broad range
Prairie Switch Grass	*Panicum virgatum*	Varies/broad range
Prairie Wild Rye	*Elymus canadensis*	Varies/broad range
Purple Coneflower	*Echinacea purpurea*	Mesic to dry soils
Rattlesnake Master	*Eryngium yuccifolium*	Varies/broad range
Rosin Weed	*Silphium integrifolium*	Varies/broad range
Rough Blazing Star	*Liatris aspera*	Mesic to dry soils
Round-Head Bush Clover	*Lespedeza capitata*	Varies/broad range
Rushes	*Juncus* spp.	Depends upon the species
Saw-Tooth Sunflower	*Helianthus grosseserratus*	Wet to mesic soils
Sedges	*Carex* spp.	Depends upon the species
Showy Goldenrod	*Solidago speciosa*	Mesic to dry soils
Side Oats Grama	*Bouteloua curtipendula*	Mesic to dry soils
Sky-Blue Aster	*Aster azureus*	Mesic to dry soils
Smooth Aster	*Aster laevis*	Mesic to dry soils
Sneezeweed	*Helenium autumnale*	Wet to mesic soils

Common Name	Botanical Name	Approximate Location*
Softsem Bulrush	*Scirpus validus creber*	Shallow water/water's edge
Spider-Wort	*Tradescantia ohiensis*	Wet to mesic soils
Stiff Goldenrod	*Solidago rigida*	Varies/broad range
Swamp Loosestrife	*Decodon verticillatus*	Shallow water/water's edge
Swamp Rose Mallow	*Hibiscus palustris*	Shallow water/water's edge
Sweet Black-Eyed Susan	*Rudbeckia subtomentosa*	Wet to mesic soils
Sweet Flag	*Acorus calamus*	Shallow water/water's edge
Tall Coreopsis	*Coreopsis tripteris*	Wet to mesic soils
Thimbleweed	*Anemone cylindrica*	Mesic to dry soils
Virginia Mountain Mint	*Pycnanthemum virginianum*	Varies/broad range
White Wild Indigo	*Baptisia leucantha*	Varies/broad range
Wild Lupine	*Lupinus perennis*	Mesic to dry soils
Wild Quinine	*Parthenium integrifolium*	Varies/broad range
Wrinkled Goldenrod	*Solidago rugosa*	Wet to mesic soils
Yellow Coneflower	*Ratibida pinnata*	Varies/broad range

** These approximate locations are very general. Each species can have specific site condition requirements (i.e. sun exposure, soil type, soil moisture). Consequently, site inspection should occur before determining an exact species list for a given site.*

7.1.3 Septic Systems/Sewers

The reliance on septic systems around the Four Lakes to treat residential wastewater is of concern. Soil maps of the area indicate that soils in the watershed are ill-suited for septic systems (Figures 7 and 8). Many of the lakes' shorelines consist of strongly sloping Riddles and Wawasee soils that should not be utilized for septic systems. Other houses are sited in Houghton muck which, given its high water table, should never be used as a septic field. In addition to these physical constraints, shoreline lot sizes do not allow for expanded septic fields to help adjust for the soils' physical limitations. In short, it is likely that many of the septic systems in the Four Lakes watershed do not adequately treat wastewater.

Overloaded or leaking septic systems deliver nutrients, pathogens, and oxygen demanding substances to the lakes. This can increase the lakes' productivity, threaten human health, and impair the lakes' habitat. The seepage of untreated or inadequately treated sewage to Holem Lake may be one of the reasons for this lake's high phosphorus levels and high algal productivity. Holem Lake's characteristics suggest the lake should possess relatively good water quality. The lake has a small watershed. Its shoreline is well vegetated protecting it from runoff and erosion. Despite these characteristics, Holem Lake exhibited poor water clarity, high phosphorus concentrations, and relatively high algal densities. Holem Lake is not the only lake in the chain on which poor septic treatment might occur. The Marshall County Health Department indicated that septic system failure rates around the lakes are higher than failure rates in other portions of Marshall County (personal communication).

There are several steps property owners can take to help minimize the problems posed by septic systems. First property owners should conduct regular septic tank maintenance. Frequency of septic tanks cleaning depends on the size of the tank and number of persons utilizing it. Jones and Yahner (1994) suggest dividing the size of the septic tank by the product of 100 and the number of persons in the household to determine the frequency of cleaning. For example, if a household of four that does not use a garbage disposal is served by an 800-gallon septic tank, this household should clean its tank every 2 years. (800/(100*4) = 2) Use of a garbage disposal increases solids loading to a septic tank by approximately 50% so this needs to be considered when calculated cleaning frequency. It is important to distinguish between "cleaning" which means the removal of solids and effluent from the tank and "pumping" which refers to removal of only the liquid effluent from the tank.

For forgetful residents, many septic companies have programs in which the company automatically comes out once a year. Residents should use extreme care when flushing household cleaners or "septic cleaners" down the drain. Many of these products interfere with, or worse, incapacitate or kill the bacteria needed to decompose the sewage. Where necessary and where possible, systems should be upgraded to ensure they can handle any increase in waste stream that has occurred over the years (i.e. modernization of the home, increases in residence time, etcetera). Water conservation measures such as using low-flow toilets or taking shorter showers will also decrease the loading to septic systems.

Alternatives to septic systems exist and should be considered. For example, wastewater wetlands typically produce cleaner effluent at the end of a leach field than traditional septic systems. This is particularly true during the summer months, when plants in such a wetland operate at peak evaporation capacity. Very little effluent leaves the wetlands. This reduction in effluent released corresponds with the peak times for potential algae blooms in the lakes. The wetland is working the hardest to prevent nutrients from reaching the lakes at the exact time nuisance algae blooms could develop if sufficient nutrients are present. Leach fields of wastewater wetlands are smaller than traditional leach fields making them more attractive on lots where space is limited. Despite this, there still may be insufficient space on some of the lots around the Four Lakes for such a system.

The installation of a sanitary sewer system is not likely to be economically feasible in the near future. Wastewater wetlands may, however, be an option for treating effluent from a group of homes. Homeowners along the southeastern shoreline of Lake Maxinkuckee utilize a wastewater wetland system (LMEC and JFNew, 2004). Wastewater is pumped from approximately 85 of 115 homes within the cluster area to the wastewater wetland located approximately three-quarters of a mile from the lake. Water discharges from the wastewater wetland system to the groundwater before returning to Lake Maxinkuckee. Concentrated housing units or new subdivisions in the area should consider the use of an expanded wastewater wetland to treat all wastewater from this area rather than relying on individual septic systems.

7.1.4 Residential and Commercial Development Erosion Control

Although little residential and commercial development is occurring in the Four Lakes watershed compared to other areas of northeast Indiana, some areas, particularly those around the watershed's lakes, continue to experience development pressure. Active construction sites are a common source of sediment to nearby waterways. Sediment loss from active construction sites can be several orders of magnitude greater than sediment loss from a completed subdivision. Use of appropriate erosion control management techniques on active construction sites is necessary to reduce pollutant loading to nearby waterbodies. During the aquatic plant survey and the watershed inspection, several shoreline areas were observed where the use of erosion control methods would have prevented or at least minimized the loss of sediment from the site. One of the areas is of particular concern since vegetated cover had been removed from the steeply sloping lawn. Several erosion control techniques, including the installation of silt fencing, creation of a construction entrance, and planting of temporary or permanent ground cover, would have helped to minimize sediment loss from this site. Four Lakes residents must be vigilant in monitoring development sites, such as this, to ensure erosion control methods are being utilized. Under new regulations, anyone planning to disturb more than an acre of land must file an erosion control plan with the state.

7.1.5 Conservation Reserve Program

The Conservation Reserve Program (CRP) is a cost-share program designed to encourage landowners to remove a portion of their land from agriculture and establish vegetation on the land in an effort to reduce soil erosion, improve water quality, and enhance wildlife habitat. The CRP targets highly erodible land or land considered to be environmentally sensitive. The CRP provides funding for a wide array of conservation techniques including set-asides, filter strips (herbaceous), riparian buffer strips (woody), grassed waterways, and windbreaks. The following paragraphs discuss some of the conservation techniques available under the CRP including filter strips, grassed waterways, and set-asides.

Filter Strips

Filter strips are typically placed adjacent to streams or roads. In the Four Lakes watershed, filter strip placement at drainage tile outlets and roadside ditches will provide the greatest water quality benefit. Filter strips slow overland flows from adjacent land and reduce runoff volume by increasing infiltration of the runoff. Slower runoff velocities and reduced flow volumes lead to decreased erosion downstream. The most important role of filter strips may, however, be their ability to remove portions of the pollutant load reaching them from adjacent agricultural areas. Many researchers have verified the effectiveness of filter strips in removing sediment from runoff with reductions ranging from 56 to 97% (Arora et al., 1996; Mickelson and Baker, 1993; Schmitt et al., 1999; Lee et al., 2000; Lee et al., 2003). Most of the reduction in sediment load occurs within the first 15 feet (4.6 m). Smaller additional amounts are retained and infiltration is increased by increasing the width of the strip (Dillaha et al., 1989). Filter strips have been found to reduce sediment-bound nutrients like total phosphorus but to a lesser extent than they reduce sediment load itself. Phosphorus is predominately associated with finer particles like silt and clay that remain suspended longer and are more likely to reach the strip's outfall (Hayes et al., 1984). Filter strips are least effective at reducing dissolved nutrient concentrations like those of nitrate, dissolved phosphorus, atrazine, and alachlor, although reductions of dissolved phosphorus, atrazine, and alachlor up to 50% have been documented (Conservation Technology Information Center, 2000). Simpkins et al. (2003) demonstrated 20-93% nitrate-nitrogen removal in multispecies riparian buffers. Short groundwater flow paths, long residence times, and contact with fine-textured sediments favorably increased nitrate-nitrogen removal rates. Additionally, up to 60% of pathogens contained in runoff may be effectively removed. Computer modeling also indicates that over the long run (30 years), filter strips significantly reduce amounts of pollutants entering waterways.

Filter strips are most effective when they: 1. are adequately sized to treat the amount of runoff reaching them; 2. include a diverse variety of species; 3. contain species appropriate for filter strips; and 4. are regularly maintained. Filter strip size depends on the purpose of the strip, but should ideally have at least a 30-foot flow path length (the minimum length across which water flows prior to reaching the adjacent waterbody). The variety of species planted in a filter strip depends upon the desired uses of the strip. For instance, if the filter strip will be grazed or if a landowner wishes to attract a diverse bird community, specific seed mixes should be used in the filter strip. The NRCS or an ecological consultant can help landowners adjust filter strip seed mixes to suit specific needs.

The need for filter strip installation is isolated to two locations in the Four Lakes watershed. These areas coincide with the special concern area located north of 12th Road between Pear and Olive Roads and the wetland protection area south of Millpond Lake where horses are grazing along a steeply-sloped hill above the wetland. The locations where filter strips are needed are marked as wetland protection and site specific in Figure 61. (More details on the site specific needs of each of the special concern areas are included in the *Site Specific Concerns Section*). Property owners should work closely with the Marshall County Soil and Water Conservation District to complete filter strip installation. Figure 61 also shows the locations where riser filters or protection is needed. (These areas are mapped as Conservation Reserve Program.) Riser filters consist of grass buffers around the riser. These riser filters function similarly to the filter strips described above. For this reason they have been included on Figure 61.

Grassed Waterways and Set-Asides

Grassed waterways are natural or constructed channels within agricultural fields that are seeded with filter vegetation and shaped and graded to carry runoff at a non-erosive velocity. Grassed waterways provide similar functions as filter strips. The grassed waterway's vegetation stabilizes the soil beneath it, holding it in place on the landscape. The vegetation slows runoff water reaching the grassed waterway, reducing the runoff water's erosive power. The vegetation also filters pollutants, particularly sediment from runoff. Like filter strips, the size and shape of the waterway along with what species are planted and how regularly the waterway is maintained determine the ability of the grassed waterway to perform these functions.

Set-asides are simply what the name implies; they are land that is "set aside" or removed from agricultural production and planted with herbaceous or woody vegetation. Like grassed waterways, they stabilize the soil on a property. Vegetation on the land set aside in CRP can also filter any runoff reaching it. More importantly, land set aside and planted to prairie or a multi-layer community (i.e. herbaceous, shrub, and tree layers) can help restore a landscape's natural hydrology. Rainwater infiltrates into the soil more readily on land covered with prairie grasses and plants compared to land supporting row crops. This reduces the erosive potential of rain and decreases the volume of runoff. Multi-layer vegetative communities intercept rainwater at different levels, further reducing the erosive potential of rain and volume of runoff.

Given the functions that grassed waterways and set-asides perform, it is not surprising that removing land from production and planting it with vegetation has a positive impact on water quality. In a review of Indiana lakes sampled from 1989 to 1993 for the Indiana Clean Lakes Program, Jones (1996) showed that lakes within ecoregions reporting higher percentages of cropland in CRP had lower mean trophic state index (TSI) scores. A lower TSI score is indicative of lower productivity and better water quality.

Field investigations conducted during this study resulted in the identification of three areas where the use of grassed waterways or conversion of at least a portion of a farm field to native prairie or other vegetation would improve water quality. These areas are mapped as CRP in Figure 61. Many of these areas are also mapped at least partially in Riddles or Wawasee soils that have severe or very severe limitations for use in agriculture due to the risk of soil erosion.

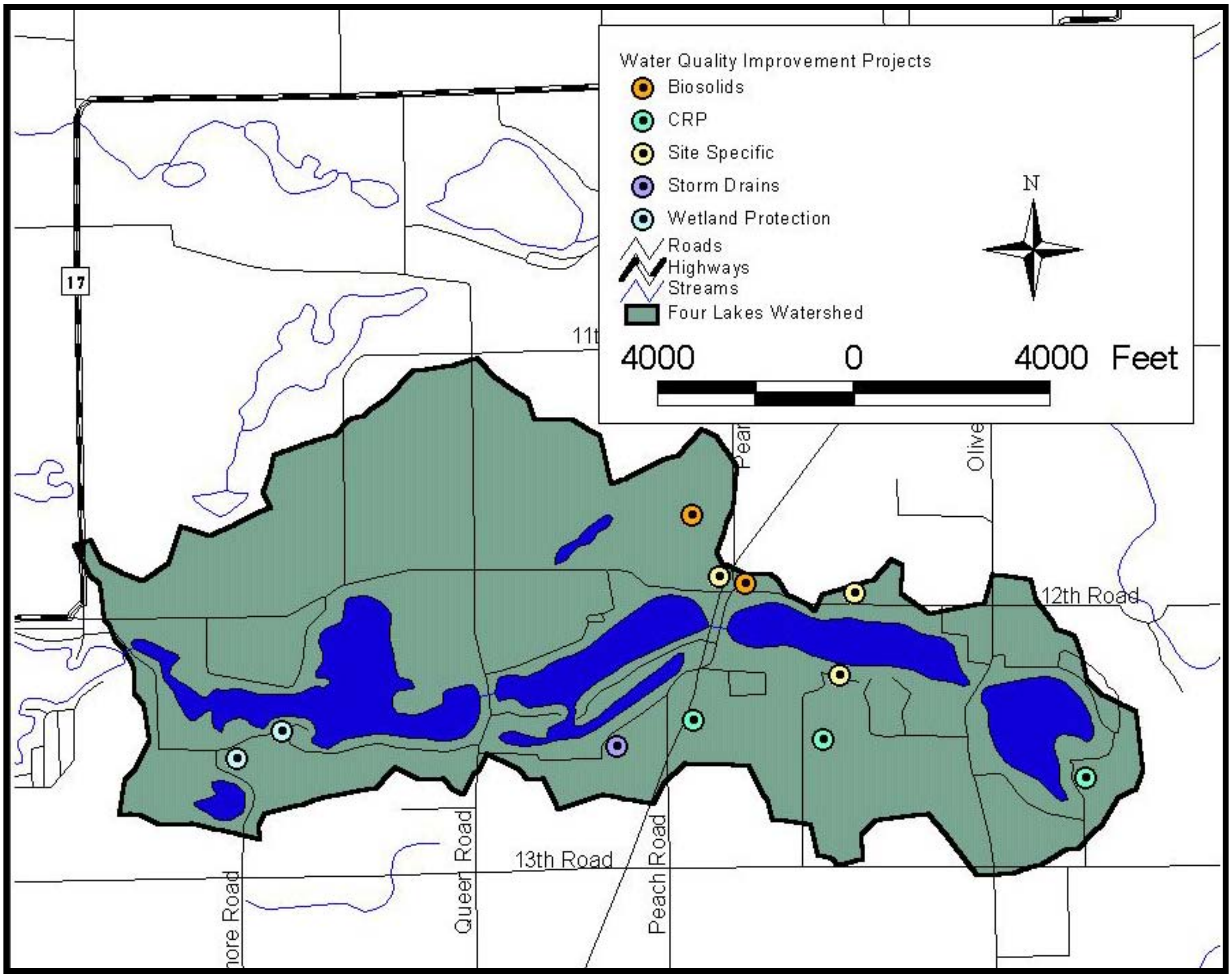

Figure 61. Locations in the Four Lakes watershed where potential water quality improvement projects were identified. Latitude and longitude coordinates are included in Appendix A.
Source: See Appendix A. Scale: 1”=4,000’.

Conservation Tillage
Removing land from agricultural production is not always feasible. Conservation tillage methods should be utilized on highly erodible agricultural land where removing land from production is not an option. Conservation tillage refers to several different tillage methods or systems that leave at least 30% of the soil covered with crop residue after planting (Holdren et al., 2001). Tillage methods encompassed by the phrase “conservation tillage” include no-till, mulch-till, and

ridge-till. The crop residue that remains on the landscape helps reduce soil erosion and runoff water volume.

Several researchers have demonstrated the benefits of conservation tillage in reducing pollutant loading to streams and lakes. A comprehensive comparison of tillage systems showed that no-till results in 70% less herbicide runoff, 93% less erosion, and 69% less water runoff volume when compared to conventional tillage (Conservation Technology Information Center, 2000). Reductions in pesticide loading have also been reported (Olem and Flock, 1990). In his review of Indiana lakes, Jones (1996) documented lower mean lake trophic state index scores in ecoregions with higher percentages of conservation tillage. A lower TSI score is indicative of lower productivity and better water quality.

Although an evaluation of the percentage of crop land on which producers were utilizing conservation tillage methods was beyond the scope of this study, county-wide estimates from tillage transect data provide a reasonable estimate of the amount of crop land on which producers are utilizing conservation tillage methods in the Four Lakes watershed. Tillage transect data collected in 2004 for Marshall County showed that the use of no-till methods on Marshall County farmland was above the statewide average for both corn and soybeans (Purdue University and IDNR, no date). Collectively, the tillage transect data suggest that, in general, producers in Marshall County could increase their use of no-till methods on farmland in the counties and, therefore, the Four Lakes watershed. The areas targeted for CRP implementation noted above should be farmed using no-till methods if removal of the land from production is not a feasible option.

7.1.6 Wetland Restoration and Protection

Visual observation and historical records indicate that a large portion of the Four Lakes watershed has been altered to increase its drainage capacity. The relatively low percentage of wetland remaining (20%) in the Four Lakes watershed compared to historical record and the location of hydric soils lends evidence to this idea. Riser tiles in low spots on the landscape and tile outlets to the Four Lakes confirm the fact that the landscape has been hydrologically altered. Shoreline development around the lakes in areas that are mapped in hydric soils also supports the hypothesis that the landscape has been hydrologically altered.

This hydrological alteration and subsequent loss of wetlands has implications for the watershed's water quality. Wetlands serve a vital role storing water and recharging the groundwater. When wetlands are drained with tiles, the stormwater reaching these wetlands is directed immediately to nearby ditches and ravines. This increases the peak flow velocities and volumes in the ditch or ravine. The increase in flow velocities and volumes can in turn lead to increased erosion in the ravine, ultimately increasing sediment delivery to downstream water bodies. Wetlands also serve as nutrient sinks at times. The loss of wetlands can increase pollutant loads reaching nearby and downstream waterbodies.

Restoring wetlands in the Four Lakes watershed could return many of the functions that were lost when these wetlands were drained. Protecting the wetlands that still exist within the Four Lakes watershed is much more likely to be feasible. Much of the southeastern portion of the Four Lakes watershed drains through a series of wetlands prior to entering Millpond Lake (Figure 10).

If maintained, these wetlands (Figure 62) will continue to provide buffering capabilities and will ultimately result in reduced sediment and sediment-attached pollutant loading to the Four Lakes. Additionally, these wetlands provide groundwater recharge and serve as nursery habitat for birds, mammals, reptiles, and amphibians. Restricting the access of horses from the western edge of this wetland will reduce nutrient loading to the wetland. The wetland complex targeted for protection is mapped in Figure 61. Specific wetland restoration sites were not identified during the watershed tour; however, hydric soils maps and aerial photographs indicate that there are areas that could be restored to wetland conditions. If landowners are interested in pursuing wetland restoration opportunities, they should contact the Marshall County NRCS office.

Figure 62. Forested wetland south of Millpond Lake that provides water filtering capacity.

7.1.7 Site Specific Concerns

Three additional areas of concern were noted as "hot spots" or locations where specific techniques could be used to improve water quality in the lakes (Figure 61). All of these locations were also identified in the Myers-Lawrence Diagnostic Study (JFNew, 2000). Conceptual water quality improvement project designs were completed for two of these sites (JFNew, 2003); however, the projects have not yet been constructed. The Four Lakes Association should work with the Myers Lake Association and the Marshall County SWCD to review the conceptual designs that have been completed and implement the projects at these sites.

The first area of concern is the farm field at the northwest corner of Pear Road and 12th Road. The concentrated flow from this field increases erosion, and thus, sediment and sediment-attached nutrient loading downstream of the field. Runoff from the field is piped under 12th Road and outlets in the woodlot on the south side of the road. A large, eroded headcut was noted at the outlet during the original survey and again during the current study. Water from the outlet has carved a channel through the woodlot (Figure 63) along the west side of Pear Road to a low spot where it is culverted under Pear Road to Myers Lake. Erosion in this channel provides a continual supply of sediment to the west end of Myers Lake. This sediment reduces the lake's storage capacity and aesthetic value and provides a substrate for emergent plant growth, which in turn interferes with recreational uses of the lake. Additionally, the influx of sediments and sediment-attached nutrients can be transported downstream to Cook Lake. This channel has also flooded Pear Road creating a safety issue for lake residents and visitors.

Figure 63. Portion of the channel downstream of the Pear and 12th Roads farm field.

The second area of concern involves the farm field along Pine Road south of Myers Lake. Soils, topographic relief, and land practices play a role in making this field a hot spot. Several highly erodible soil units are mapped on the field. Because of the site characteristics associated with this field, traditional agricultural practices create a high potential for soil erosion. Furthermore, eroded streambanks in the channel downstream of the field and several wash outs that occurred at the culvert under Happy Acres Trail indicate that there is high potential for the delivery of sediment and sediment-attached nutrients from the farm field to Myers Lake (Figure 64).

Figure 64. Culvert under Happy Acres Trail with noticeable sediment deposition. This sediment and any sediment-attached nutrients can reach Myers Lake.

The final area of concern is located where wastewater treatment plant sludge or biosolids are spread on the agricultural land north of 12th Road. While, only a portion of the fields where sludge is spread lies within the Four Lakes watershed, this practice has the potential to deliver additional nutrients to the Four Lakes watershed via drainage tiles. Only one tile leading directly from a portion of these fields to the lakes within the watershed could be identified. This tile runs under 12th Road and outlets in a swale leading to Myers Lake. The grassed area at the tile's outlet filters some of the runoff water, but during large rain events, it is likely that some nutrients reach Myers Lake. These nutrients will fertilize the plants growing at the lake's edge and the algae growing throughout the water column. Drainage tiles from the other fields to Myers or Cook Lakes were not identified. Residents should work with the landowners to identify any tiles leading from these agricultural fields and install filter strips or water and sediment control basins (WASCOBs) to intercept runoff from these fields before it enters any of the lakes within the Four Lakes watershed.

7.2 In-Lake Management

7.2.1 Alum Treatment

Phosphorus precipitation and inactivation is designed to remove phosphorus from the water column *and* to prevent release of phosphorus from sediments. This nutrient control strategy is aimed at minimizing planktonic algal growth. The treatment involves adding aluminum salts to the lake. These salts form a floc or an agglomeration of small particles. This floc (e.g. $Al(OH)_3$) acts in two ways: (a) it absorbs phosphorus from the water column as it settles, and (b) it seals the bottom sediments if a thick enough layer has been deposited. Phosphorus can also precipitate out as an aluminum salt (e.g. $AlPO_4$).

Most phosphorus precipitation treatments employ liquid aluminum sulfate (alum) or sodium aluminate. The dosages are determined by a standard jar test, keeping in mind that aluminum solubility is lowest in the pH range of 6.0 to 8.0. Cooke and Kennedy (1981) offer a detailed dose determination method. Aluminum toxicity does not appear to be a problem at treatment concentrations in well-buffered lakes as long as the pH remains above 6.0. Chemicals added for phosphorus control are applied either to the lake surface or to the hypolimnion, depending upon whether water column or sediment phosphorus control is most necessary.

The application procedure of aluminum salts to lake water has changed little since the first treatment in Horseshoe Lake, Wisconsin (Peterson et al., 1973). At Horseshoe Lake, alum slurry was pumped from a barge through a manifold pipe that trailed behind the vessel just below, and perpendicular to, the water surface. Today, new LORAN-guided high-speed barges applying 4060 ft^3 (115 m^3) of liquid alum per day are the most advanced application vessels available (Cooke et al., 1993).

The season of application is critical for phosphorus removal, since different forms of phosphorus predominate in the water column on a seasonal basis. Phosphorus removal is most effective in early spring or late fall when most phosphorus is in an inorganic form that can be removed almost entirely by the floc.

Phosphorus precipitation and inactivation is most effective in lakes with long hydraulic residence times and low watershed phosphorus loading (Olem and Flock, 1990). In lakes with short residence times, new water from the watershed is continually replacing the water in a lake basin. If this water contains a high phosphorus load, the new phosphorus immediately replaces the phosphorus that was precipitated out of the water column. This new phosphorus also promotes the growth of algae and rooted plants. When these organisms die and sink to the lake's bottom, they form a new sediment layer over the alum treatment's seal. The seal is not able to prevent the release of phosphorus from the dead organisms that have settled on top of it.

Regardless of the lake hydraulic residence time, decomposition of aquatic organisms and sedimentation will naturally occur within a lake. This limits the alum treatment's effectiveness to approximately five to ten years (Olem and Flock, 1990). In some lakes, the phosphorus inactivation has been effective for as long as twelve years. The treatment's expected length of effectiveness should always be weighed against its cost. Costs vary depending upon the location and size of lake, type of applicator barge utilized for treatment, and other factors. Cooke et al. (1993) report a cost of approximately $1,600 per acre ($640/ha) using a newer (faster) barge applicator.

An alum treatment should always be performed by an experienced applicator. An experienced applicator will test chemical conditions in the lake to ensure parameters are within ranges necessary to attempt a treatment (i.e. sufficient buffering capacity and water hardness). In addition, an experienced applicator will monitor the lake during treatment to ensure that the pH of the lake does not fall below 5.5-6.0. Below this pH range, conditions are appropriate for the formation of Al^{3+}, which is toxic to many organisms.

Cooke et al. (1993) outline several of the potential drawbacks to alum treatments. These include the potential for increased rooted plant growth. As phosphorus that was once available for algae growth is removed from the water column, algae growth is reduced. This may increase water transparency. Increased water clarity allows for greater light penetration which could enhance rooted plant growth. Food chain impacts from the immediate reduction of algae could also affect a lake's fishery. Finally, the toxicity of aluminum even in neutral or basic conditions (pH >7) is of some concern to researchers.

Holem Lake is a prime candidate for an alum treatment in the future. This lake currently has the lowest Secchi disk transparency and a relatively high concentration of total phosphorus. The internal load of phosphorus that results from Holem Lake's anoxic hypolimnion creates less than ideal conditions. For now, the released phosphorus only reaches the surface waters (where the algae are) during spring and fall turnover or in other words times when algal growth is limited due to cool temperatures and low seasonal light. Over time, the epilimnetic phosphorus concentration in Holem Lake will gradually increase, eventually reaching the point where regular and persistent algae blooms are the norm. Cook and Kreighbaum Lakes may also be candidates for an alum treatment; however, the lakes' shorter residence times limits the longevity of an alum treatment.

7.2.2 Dredging

Sediment removal by dredging removes phosphorus enriched sediments from lake bottoms, thereby reducing the likelihood of phosphorus release from the sediments. Dredging also deepens lakes for recreational purposes and limits the growth area for rooted macrophytes. Because this technique is capital-intensive, it can only be justified in small lakes or in lakes where the sediment-bound phosphorus is limited to a small, identifiable area. Dredging is not effective in lakes where additional sediment loading cannot be controlled. Sediment removal might be justified in a seepage lake, where watershed controls are not applicable.

A potentially troublesome consequence of dredging is the resuspension of sediments during the dredging operation and the possible release of toxic substances bound loosely to sediments. Because of this, sediment cores must be analyzed prior to dredging to determine sediment composition. Such an analysis would also provide a profile of phosphorus concentrations with depth in the sediments. If phosphorus concentrations do not decline with depth, dredging for phosphorus control would not be effective since phosphorus could continue to be released from the sediments.

Cost must be carefully evaluated before dredging operations occur. In deep lakes, the cost of dredging can be prohibitive. In small lakes, it may be easier and more cost-effective to dewater the lake and remove sediments with front end loaders and trucks. Perhaps the most economically and logistically prohibitive part of a dredging operation is disposal of the removed sediments. Sediment disposal must be investigated *before* the decision to dredge can be made. Dredging costs range from $15,000 to $20,000 per acre ($37,000 to $49,400 per hectare, Jeff Krevda, Dredging Technologies, personal communication). This estimate excludes the costs of transportation to a disposal site and purchase of the disposal site if one is not available for free. Any dredging activities in a freshwater public lake will require permits from the Corps of Engineers, the Indiana Department of Environmental Management, and Indiana Department of Natural Resources, further increasing the cost of dredging.

At this point, dredging is not recommended since the IDNR is unlikely to approve dredging to deepen naturally shallow areas. Dredging may be acceptable if it is determined that the lack of access between Cook and Millpond Lakes is due to an accumulation of organic debris that can be removed without causing significant disturbance to the lakes' ecology. More investigation is needed to determine this.

One good avenue for continued investigation of this issue is the Lake and River Enhancement Program's new sediment removal program. Under the Lake and River Enhancement sediment removal program, applicants have to complete a dredging plan in order to qualify for funding. This dredging plan would be the ideal avenue for understanding dredging needs on the lakes. The Four Lakes Lake Association has already identified areas where recreation is impaired and dredging may be a solution. These areas correspond with areas identified for plant treatment and are mapped in Figure 47 and 48. Before any dredging or sediment removal planning begins, the Four Lakes Lake Association should consult with local IDNR fisheries biologists to determine if dredging of desired areas is feasible.

7.2.3 Monitoring

As noted in the *Lake Assessment Section* of this document, many of the Four Lakes possess relatively sparse historical data. The Four Lakes Lake Association currently participates in the Indiana Clean Lakes Volunteer Monitoring Program. The Indiana Clean Lakes Volunteer Monitoring Program trains and equips citizen volunteers to measure Secchi disk transparency, water color, total phosphorus, and chlorophyll *a* in Indiana lakes. Citizen volunteers monitor over 115 lakes for transparency and 40 lakes for phosphorus and chlorophyll. Transparencies of the Four Lakes are currently monitored by volunteers. The Four Lakes would also benefit from regular monitoring of total phosphorus and chlorophyll *a* concentrations. The additional data on the lakes would help elucidate any trends in water quality and provide more timely information with which lake management decisions can be made.

8.0 RECOMMENDATIONS

Data collected during this study indicate that management efforts should first focus on watershed improvement and implement in-lake management techniques only after external sources of pollutants, particularly phosphorus, have been controlled. Each of the lakes has a relatively short hydraulic residence time. For example, Kreighbaum Lake's residence time is moderately short at 288 days. This means that every 288 days the entire volume of water in Kreighbaum Lake is flushed and replaced with new water from its inlet. Thus, improving the water entering Kreighbaum Lake is more cost-effective than treating the water that exists in the lake since the lake is continually replenished with new water from its watershed. The same is true for Cook and Millpond Lakes.

Fewer than fifteen management actions were identified in the Four Lakes watershed over the course of this study. Data collected during the study suggest that management efforts along the immediate shoreline of the Four Lakes should be prioritized over work in larger watershed. Although each lake possesses a relatively small watershed, it is important to focus watershed work in one specific area before moving on to other locations. Therefore, watershed efforts should focus on Cook and Holem Lakes before beginning work on the other two lakes. Cook Lake contains the highest total phosphorus concentration, possesses a large portion of anoxic water, and readily releases phosphorus from its sediment. Holem Lake possesses the lowest transparency and the highest density plankton community. Collectively, this evidence suggests work in these two subwatersheds should receive a higher priority over other areas in the watershed.

Management efforts in the Kreighbaum subwatershed draining should receive priority after projects in the Cook and Holem Lake subwatersheds. All of these lakes drain into Millpond Lake; therefore, improving water quality entering and within Cook, Holem, and Kreighbaum Lakes will ultimately improve water quality within Millpond Lake as well.

When implementing any of the following recommendations, watershed stakeholders should remember that the restoration of Cook, Holem, Kreighbaum, and Millpond Lakes and their watershed will require a long-term, concerted effort. The lake and watershed characteristics of the study lakes do not point to a single "smoking gun" responsible for the moderately high productivity or relatively poor water quality. Thus, the installation of a single buffer strip, restoration of a single wetland, utilization of conservation tillage on a single field, or implementation of erosion control methods on a single residential construction site will have little noticeable effect on study lakes' water quality. Restoration of the Four Lakes will only be achieved by the implementation of these recommendations across the watershed over the long term.

The following is a list of prioritized recommendations for improving water quality in the Four Lakes watershed. The prioritization is based on the current ecological conditions of the study lakes and their watershed. These conditions may change as land and lake uses change. Watershed stakeholders may also wish to prioritize these management recommendations differently to accommodate specific needs or desired uses of the lakes in the Four Lakes chain. It is also important for watershed stakeholders to know that action need not be taken in this order. Some of the smaller, less expensive recommendations, such as the individual property owner recommendations, may be implemented while funds are being raised to implement some of the larger projects. Many of the larger projects will require feasibility studies to ensure landowner willingness to participate in the project and regulatory approval of the project. As such, specific timelines and cost estimates are not included for each recommendation.

Lake and Watershed Recommendations

1. Complete an aquatic plant management plan for the Four Lakes. The plan should provide management alternatives for each of the primary concerns identified during the plant survey. The plan must also consider and/or include Myers and Lawrence Lakes as these are ecologically linked with the Four Lakes.

2. Implement a biological control program for purple loosestrife and investigate the usage of a biological control for Eurasian water milfoil within each of the Four Lakes. Begin these programs only after an aquatic plant management plan has been completed for each of the lakes or the chain of lakes as a whole.

3. Implement individual property owner management techniques. These apply to all watershed property owners rather than simply those who live adjacent to the Four Lakes.
    a. Reduce the frequency and amount of fertilizer, herbicide, or pesticide used for lawn care.
    b. Use only phosphorus-free fertilizer. (This means that the middle number on the fertilizer package listing the nutrient ratio, nitrogen:phosphorus:potassium is 0.)
    c. Consider re-landscaping lawn edges, particularly those along the watershed's lakes, to include low profile prairie species that are capable of filtering runoff water better than turf grass.
    d. Consider resurfacing concrete or wooden seawalls with glacial stone, then planting native emergent vegetation along shorelines or in front of resurfaced or existing concrete or wooden seawalls to provide fish and invertebrate habitat and dampen wave energy.
    e. Keep organic debris like lawn clippings, leaves, and animal waste out of the water.
    f. Properly maintain septic systems. Systems should be pumped regularly and leach fields should be properly cared for.

g. Examine all drains that lead from roads, driveways, or rooftops to the watershed's lakes; consider alternate routes for these drains that would filter pollutants before they reach the water.
h. Obey speed limits throughout the lakes.
i. Clean boat propellers after lake use and refrain from dumping bait buckets into the lake to prevent the spread of exotic species.

4. Post informational signage at the boat launch on Millpond Lake and at the private launches on Cook and Holem Lakes to inform lake users of best management practices to prevent the spread of aquatic nuisance species, particularly Eurasian water milfoil. Any signage posted at a public boat launch required permission from the IDNR Division of Fish and Wildlife.

5. Treat the common reed and reed canary grass along Holem Lake's southern shoreline (Figure 44). These species spread rapidly creating monocultures. Treatment should occur before these species spread to other shorelines around the Four Lakes.

6. Identify field tiles or drains draining from agricultural fields where wastewater treatment plant biosolids are applied to the Four Lakes. The fields are identified in Figure 61.

7. Protect and preserve watershed wetlands, specifically those identified in Figure 61, so that they will continue to provide water quality filtration, groundwater recharge, and biotic habitat for the Four Lakes and their watershed.

8. Work with the Myers Lake Association to complete the installation of conceptually designed water quality improvement projects identified as special projects in Figure 61. The Indiana Lakes Management Society Small Grants Program or funding from the Marshall County SWCD should be available to assist with associated project cost with these projects.

9. Encourage landowners to enroll agricultural fields in the Conservation Reserve Program or to utilize conservation tillage on the identified farm fields (Figure 61). The Marshall County NRCS should be able to assist the lake association with these endeavors.

Additional Considerations

1. In the future, consider installation of a sewer system, alternate wastewater treatment system, or wastewater cluster system around the Four Lakes.

2. Consider becoming an expanded volunteer monitor with the Indiana Clean Lakes Volunteer Monitoring Program. Expanded monitors collect water quality samples for total phosphorus and chlorophyll *a* analysis in addition to their routine Secchi disk transparency monitoring.

3. Continue implementation of recommendations made in previous watershed studies.

4. Following implementation of several watershed management techniques, re-assess the lakes and determine whether in-lake management should be considered.

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APPENDICES

FOUR LAKES WATERSHED DIAGNOSTIC STUDY
MARSHALL COUNTY, INDIANA

APPENDIX A:

GEOGRAPHIC INFORMATION SYSTEMS (GIS) MAP DATA SOURCES

FOUR LAKES WATERSHED DIAGNOSTIC STUDY MARSHALL COUNTY, INDIANA

Appendix A. Geographic Information Systems (GIS) map data sources.

Figure 2. The Four Lake watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set.

Figure 3. Four Lakes subwatersheds.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Watershed and subwatershed boundaries were delineated based using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI.

Figure 4. Topographic relief of the Four Lakes watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Relief coverage is the U.S. Geological Survey National Elevation Data set.

Figure 5. Highly erodible and potentially highly erodible soils within the Four Lakes watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Highly erodible and potentially soils criteria were set by the NRCS.

Figure 6. Soil septic tank suitability within the Four Lakes watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Soil septic tank limitations were set by the NRCS and are reported in Smallwood (1980).

Figure 9. Land use in the Four Lakes watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Land use comes from the USGS Indiana Land Cover Data Set. The data set was corrected based on 2003 aerial photographs.

Figure 10. Wetlands in the Four Lakes watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Wetland location source is U.S. Fish and Wildlife Service National Wetland Inventory GIS coverage.

Figure 11. Hydric soils in the Four Lakes watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Hydric soil classifications were previously set by the NRCS.

Figure 15. Shoreline surface type observed at Cook and Holem Lake, August 6, 2004.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Shoreline surface coverages are based on field surveys conducted August 6, 2004 and were drawn by JFNew.

Figure 21. Shoreline surface type observed at Kreighbaum and Millpond Lakes, August 6, 2004.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Shoreline surface coverages are based on field surveys conducted August 6, 2004 and were drawn by JFNew.

Figure 43. Cook and Holem Lake plant beds as mapped August 6, 2004.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Plant bed coverages are based on field surveys conducted August 6, 2004 and were drawn by JFNew.

Figure 44. Kreighbaum and Millpond Lake plant beds as mapped August 6, 2004.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Plant bed coverages are based on field surveys conducted August 6, 2004 and were drawn by JFNew.

Figure 45. Exotic aquatic plant species locations within Cook and Holem Lakes as mapped August 6, 2004.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Exotic species coverages are based on field surveys conducted August 6, 2004 and were drawn by JFNew.

Figure 46. Exotic aquatic plant species locations within Kreighbaum and Millpond Lakes as mapped August 6, 2004.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Exotic species coverages are based on field surveys conducted August 6, 2004 and were drawn by JFNew.

Figure 47. Priority aquatic plant treatment areas identified by residents for Cook and Holem Lakes.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Priority aquatic plant treatment area coverages are based on field surveys conducted August 6, 2004 and were drawn by JFNew.

Figure 48. Priority aquatic plant treatment areas identified by residents for Kreighbaum and Millpond Lakes.
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Priority aquatic plant treatment area coverages are based on field surveys conducted August 6, 2004 and were drawn by JFNew.

Figure 62. Locations in the Four Lakes watershed where potential water quality improvement projects were identified.

Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Improvement project locations are based upon field surveys conducted by JFNew. Coverages were drawn by JFNew. Latitude and longitude coordinates for potential water quality improvement projects are listed below.

Latitude and longitude coordinates for potential water quality improvement projects.

Recommendation	northing	easting
Wetland protection	550718.3	4571669.6
Wetland protection	551000.5	4571838.9
Storm Drains	553077.0	4571748.6
CRP	553551.0	4571906.6
CRP	554352.3	4571793.8
CRP	555977.4	4571556.8
Site Specific	554544.2	4572696.6
Biosolids	553867.0	4572753.0
Biosolids	553539.7	4573181.9
Site Specific	553709.0	4572798.2
Site Specific	554453.9	4572188.8

APPENDIX B:

ENDANGERED, THREATENED, AND RARE SPECIES LIST, FOUR LAKES WATERSHED

FOUR LAKES WATERSHED DIAGNOSTIC STUDY MARSHALL COUNTY, INDIANA

Endangered, Threatened and Rare Species, High Quality
Natural Communities and Significant Natural Areas
Documented from the Four Lakes Watershed area,

Type	Species Name	Common Name	State	Fed	Location	Date
DONALDSON						
Wetland	WETLAND - FEN	FEN	SG	**	T33NR01E 22 SWQ	1985
PLYMOUTH						
Mollusk	CAMPELOMA DECISUM	POINTED CAMPELOMA	SSC	**	T33NR02E 19 NEQ SEQ NWQ	1988
Fish	COREGONUS ARTEDI	CISCO	SSC	**	T33NR02E 19 EH	1994
Fish	COREGONUS ARTEDI	CISCO	SSC	**	T33NR02E 19 NH NWQ	1988
MENOMINEE WETLAND CONSERVATION AREA						
Mammal	TAXIDEA TAXUS	AMERICAN BADGER	SE	**	T33NR01E 12 & 13	1988

APPENDIX C:

ENDANGERED, THREATENED, AND RARE SPECIES LIST, MARSHALL COUNTY, INDIANA

FOUR LAKES WATERSHED DIAGNOSTIC STUDY MARSHALL COUNTY, INDIANA

November 12, 1999

ENDANGERED, THREATENED AND RARE SPECIES DOCUMENTED FROM MARSHALL COUNTY, INDIANA

SPECIES NAME	COMMON NAME	STATE	FED	SRANK	GRANK
VASCULAR PLANT					
ARMORACIA AQUATICA	LAKE CRESS	SE	**	S1	G4?
ASTER BOREALIS	RUSHLIKE ASTER	SR	**	S2	G5
COELOGLOSSUM VIRIDE VAR VIRESCENS	LONG-BRACT GREEN ORCHIS	ST	**	S2	G5T5
CYPRIPEDIUM CANDIDUM	SMALL WHITE LADY'S-SLIPPER	SR	**	S2	G4
ELEOCHARIS EQUISETOIDES	HORSE-TAIL SPIKERUSH	SE	**	S1	G4
GLYCERIA GRANDIS	AMERICAN MANNA-GRASS	SX	**	SH	G5
HYPERICUM PYRAMIDATUM	GREAT ST. JOHN'S-WORT	SE	**	S1	G4
PLATANTHERA ORBICULATA	LARGE ROUNDLEAF ORCHID	SX	**	SX	G5?
POA ALSODES	GROVE MEADOW GRASS	SR	**	S2	G4G5
POTAMOGETON STRICTIFOLIUS	STRAIGHT-LEAF PONDWEED	SE	**	S1	G5
VALERIANA EDULIS	HAIRY VALERIAN	SE	**	S1	G5
ZANNICHELLIA PALUSTRIS	HORNED PONDWEED	SE	**	S1	G5
MOLLUSCA: GASTROPODA					
CAMPELOMA DECISUM	POINTED CAMPELOMA	SSC	**	S2	G5
LYMNAEA STAGNALIS	SWAMP LYMNAEA	SSC	**	S2	G5
MOLLUSCA: BIVALVIA (MUSSELS)					
ALASMIDONTA VIRIDIS	SLIPPERSHELL MUSSEL	**	**	S2	G4G5
LAMPSILIS FASCIOLA	WAVY-RAYED LAMPMUSSEL	SSC	**	S2	G4
LIGUMIA RECTA	BLACK SANDSHELL	**	**	S2	G5
PLEUROBEMA CLAVA	CLUBSHELL	SE	LE	S1	G2
PTYCHOBRANCHUS FASCIOLARIS	KIDNEYSHELL	SSC	**	S2	G4G5
FISH					
COREGONUS ARTEDI	CISCO	SSC	**	S2	G5
ETHEOSTOMA PELLUCIDUM	EASTERN SAND DARTER	SSC	**	S2	G3
ICHTHYOMYZON BDELLIUM	OHIO LAMPREY	**	**	S2	G3G4
REPTILES					
CLEMMYS GUTTATA	SPOTTED TURTLE	SE	**	S2	G5
CLONOPHIS KIRTLANDII	KIRTLAND'S SNAKE	SE	**	S2	G2
EMYDOIDEA BLANDINGII	BLANDING'S TURTLE	SE	**	S2	G4
SISTRURUS CATENATUS CATENATUS	EASTERN MASSASAUGA	SE	**	S2	G3G4T3T4
TERRAPENE ORNATA	ORNATE BOX TURTLE	SE	**	S2	G5
THAMNOPHIS BUTLERI	BUTLER'S GARTER SNAKE	SE	**	S1	G4
BIRDS					
ACCIPITER STRIATUS	SHARP-SHINNED HAWK	SSC	**	S2B,SZN	G5
ARDEA HERODIAS	GREAT BLUE HERON	**	**	S4B,SZN	G5
BOTAURUS LENTIGINOSUS	AMERICAN BITTERN	SE	**	S2B	G4
CERTHIA AMERICANA	BROWN CREEPER	**	**	S2B,SZN	G5

STATE: SX=extirpated, SE=endangered, ST=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant,** no status but rarity warrants concern

FEDERAL: LE=endangered, LT=threatened, LELT=different listings for specific ranges of species, PE=proposed endangered, PT=proposed threatened, E/SA=appearance similar to LE species, **=not listed

November 12, 1999

ENDANGERED, THREATENED AND RARE SPECIES DOCUMENTED FROM MARSHALL COUNTY, INDIANA

SPECIES NAME	COMMON NAME	STATE	FED	SRANK	GRANK
CISTOTHORUS PALUSTRIS	MARSH WREN	SE	**	S3B,SZN	G5
DENDROICA CERULEA	CERULEAN WARBLER	SSC	**	S3B	G4
IXOBRYCHUS EXILIS	LEAST BITTERN	SE	**	S3B	G5
RALLUS ELEGANS	KING RAIL	SE	**	S1B,SZN	G4G5
RALLUS LIMICOLA	VIRGINIA RAIL	SSC	**	S3B,SZN	G5
WILSONIA CITRINA	HOODED WARBLER	SSC	**	S3B	G5
XANTHOCEPHALUS XANTHOCEPHALUS	YELLOW-HEADED BLACKBIRD	SE	**	S1B	G5
MAMMALS					
SPERMOPHILUS FRANKLINII	FRANKLIN'S GROUND SQUIRREL	SE	**	S2	G5
TAXIDEA TAXUS	AMERICAN BADGER	SE	**	S2	G5
HIGH QUALITY NATURAL COMMUNITY					
PRAIRIE - MESIC	MESIC PRAIRIE	SG	**	S2	G2
WETLAND - BEACH MARL	MARL BEACH	SG	**	S2	G3
WETLAND - BOG ACID	ACID BOG	SG	**	S2	G3
WETLAND - FEN	FEN	SG	**	S3	G3
WETLAND - FLAT MUCK	MUCK FLAT	SG	**	S2	G2

STATE: SX=extirpated, SE=endangered, ST=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant,** no status but rarity warrants concern

FEDERAL: LE=endangered, LT=threatened, LELT=different listings for specific ranges of species, PE=proposed endangered, PT=proposed threatened, E/SA=appearance similar to LE species, **=not listed

APPENDIX D:

MACROPHYTE INVENTORY DATA SHEETS

FOUR LAKES WATERSHED DIAGNOSTIC STUDY
MARSHALL COUNTY, INDIANA

Abbreviation	Plant Species	Common Name	Stratum	Cook	Holem	Kreighbaum	Mill Pond
ACESAI	*Acer saccharinum*	Silver maple	Emergent	X	X		
ALISUB	*Alisma subcordatum*	Small water plantain	Emergent		X		
ASCINC	*Asclepias incarnata*	Swamp milkweed	Emergent		X		
BIDCER	*Bidens cernua*	Nodding bur marigold	Emergent			X	
BIDCOM	*Bidens comosa*	Swamp tickweed	Emergent		X		
BOECYC	*Boehmeria cylindrica*	False nettle	Emergent		X		
BRASCH	*Brasenia schreberi*	Water shield	Floating		X		
CEPOCC	*Cephalanthus occidentalis*	Buttonbush	Emergent				X
CERDEM	*Ceratophyllum demersum*	Coontail	Submergent	X	X	X	X
CHASP	*Chara species*	Chara species	Submergent	X	X	X	X
CXSP	*Carex species*	Sedge species	Emergent			X	
CYPSP	*Cyperus species*	Sedge species	Emergent				X
CYPESC	*Cyperus esculentus*	Yellow nut sedge	Emergent			X	
DECVER	*Decodon verticillatus*	Whirled loosestrife	Emergent	X	X	X	X
DRYTHP	*Dryopteris thelypteris*	Marsh shield fern	Emergent	X	X		
ELESP	*Eleocharis species*	Rush species	Emergent	X	X		
ELOCAN	*Elodea canadensis*	Common water weed	Submergent	X			X
EUPPER	*Eupatorium perfoliatum*	Common boneset	Emergent		X		
FILALG	*Filamentous algae*	Filamentous algae	Algae	X	X	X	X
HETDUB	*Heteranthera dubia*	Water star grass	Emergent		X		
IMPCAP	*Impatiens capensis*	Spotted jewelweed	Emergent	X	X		X
IRIVIS	*Iris versicolor*	Blue flag iris	Emergent	X			X
JUGNIG	*Juglans nigra*	Black walnut	Emergent		X		
LEEORY	*Leersia oryzoides*	Rice cut grass	Emergent	X	X		
LEMMIO	*Lemna minor*	Common duckweed	Floating	X	X	X	X
LEMTRI	*Lemna trisulca*	Star duckweed	Floating	X	X	X	X
LYTSAL	*Lythrum salicaria*	Purple loosestrife	Emergent	X	X	X	X
MYREXA	*Myriophyllum exalbescens*	Northern water milfoil	Submergent			X	
MYRSPI	*Myriophyllum spicatum*	Euasian water milfoil	Submergent	X	X	X	X
NAJGUA	*Najas guadalupensis*	Southern naiad	Submergent	X		X	X
NUPADV	*Nuphar advena*	Spatterdock	Floating	X	X	X	X
NYMTUB	*Nyphaea tuberosa*	White water lily	Floating	X	X	X	X
PELVIR	*Peltandra virginica*	Arrow arum	Emergent	X	X	X	X
PHAARU	*Phalarus arundinacaea*	Reed canary grass	Emergent	X	X		
PHRAUS	*Phragmites australis*	Common reed	Emergent		X		
POLHYS	*Polygonum hydropiperoides*	Mild water pepper	Emergent		X		X
POLLAP	*Polygonum lapathifolia*	Nodding smartweed	Emergent	X			X
POLPER	*Polygonum persicaria*	Lady's thumbprint	Emergent		X	X	
POLPUN	*Polygonum punctatum*	Dotted smartweed	Emergent		X		
PONCOR	*Pontedaria cordata*	Pickerel weed	Emergent	X	X	X	X
POPDEL	*Populus deltoides*	Cottonwood	Emergent		X		
POTAMP	*Potamogeton amplifolium*	Large-leaf pondweed	Submergent	X		X	X
POTCRI	*Potamogeton crispus*	Curly leaf pondweed	Submergent	X		X	X
POTFOL	*Potamogeton foliosis*	Leafy pondweed	Submergent			X	X
POTGRA	*Potamogeton gramineus*	Grassy pondweed	Submergent			X	
POTILL	*Potamogeton illinoiensis*	Illinois pondweed	Submergent		X	X	X
POTNAT	*Potamogeton natans*	Floating-leaf pondweed	Submergent			X	
POTNOD	*Potamogeton nodosus*	Long-leaf pondweed	Submergent		X		X
POTPEC	*Potamogeton pectinatus*	Sago pondweed	Submergent	X		X	X
POTPUS	*Potamogeton pusillus*	Small pondweed	Submergent	X	X	X	X
POTZOS	*Potamogeton zosteriformis*	Flat-stem pondweed	Submergent			X	X
RHUVER	*Rhus vernix*	Poison sumac	Emergent	X	X	X	X

Abbreviation	**Plant Species**	**Common Name**	**Stratum**	**Cook**	**Holem**	**Kreighbaum**	**Mill Pond**
ROSPAL	*Rosa palustris*	Swamp rose	Emergent		X		
SAGLAT	*Sagittaria latifolia*	Broad leafed arrowhead	Emergent	X	X		X
SALSP	*Salix species*	Willow species	Emergent	X	X		X
SCIACU	*Scirpus acutus*	Hardstem bulrush	Emergent		X	X	
SCIPUN	*Scirpus pungens*	Chairmakers rush	Emergent			X	
SCISUB	*Scirpus subterminalis*	Subterminate bulrush	Emergent			X	
SCIVAL	*Scirpus validus*	Softstem bulrush	Emergent	X	X		
SOLDUL	*Solanum dulcomera*	Climbing nightshade	Emergent		X		
SPIPOL	*Spirodela polyrhiza*	Large duckweed	Floating	X	X	X	X
TYPANG	*Typha angustifolia*	Narrow leafed cattail	Emergent	X	X	X	X
TYPGLA	*Typha glauca*	Hybrid cattail	Emergent		X	X	X
TYPLAT	*Typha latifolia*	Broad leafed cattail	Emergent	X	X	X	X
ULMAME	*Ulmus americana*	American elm	Emergent		X		
UTRGIB	*Utricularia gibba*	Creeping bladderwort	Submergent	X	X	X	X
UTRVUL	*Utricularia vulgaris*	Great bladderwort	Submergent	X	X	X	X
VIBSP	*Vibernum species*		Emergent		X		
WOLCOL	*Wolffia columbiana*	Water meal	Floating	X	X	X	X

Aquatic Vegetation Reconnaissance Sampling

Waterbody Cover Sheet

Surveying Organization: JFNew

Waterbody Name: Cook Lake

Lake ID:

County: Marshall

Date: August 6, 2004

Habitat Stratum: IL

Ave. Lake Depth (ft): 17.7

Lake Level:

GPS Metadata

Crew Leader: S. Peel

Datum:	Zone:	Accuracy:
UTM NAD 1983	16	<2m

Recorder: S. Namestnik

Method: Trimble PRO XRS

Secchi Depth (ft): 6.2

Total # of Plant Beds Surveyed: 1

Total # of Species: 36

Littoral Zone Size (acres): 53.6

❑ Measured

✓ Estimated

Littoral Zone Max. Depth (ft): 18.6

❑ Measured

❑ Estimate (historical Secchi)

✓ Estimated (current Secchi)

Notable Conditions:

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: 8/6/04**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Cook Lake				Center of the Bed
Bed Size:					Latitude: 41°18'01"
Substrate: muck	Waterbody ID:				Longitude: 86°22'12"
Marl?	Total # of Species: 36				Max. Lakeward Extent of Bed
High Organic? Yes	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 2	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID	
ACESAI	1				
CERDEM	2				
CHASP	1				
DECVER	2				
DRYTHP	1				
ELESP	1				
ELOCAN	1				
FILALG	2				
IMPCAP	1				
IRIVIS	1				
LEEORY	1				
LEMMIO	1				
LEMTRI	1				
LYTSAL	2				
MYRSPI	3				
NAJGUA	1				
NUPADV	2				
NYMTUB	3				
PELVIR	1				
POLHYS	1				
POLLAP	1				
PONCOR	1				

Individual Plant Bed Survey

Comments: "QE" value is always 0.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or
letter to denote specific
location of a species;
referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: 8/6/04**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Cook Lake				Center of the Bed
Bed Size:					Latitude: 41°18'01"
Substrate: muck	Waterbody ID:				Longitude: 86°22'12"
Marl?	Total # of Species: 36				Max. Lakeward Extent of Bed
High Organic? Yes	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 2	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Individual Plant Bed Survey

Species Code	Abundance	QE	Vchr.	Ref. ID
POTAMP	1			
POTCRI	1			
POTPEC	1			
POTPUS	1		1	
RHUVER	1			
SAGLAT	1			
SALSP	1			
SCIVAC	1			
SPIPOL	1			
TYPANG	1			
TYPLAT	2			
UTRGIB	1			
UTRVUL	1			
WOLCOL	2			

Comments: "QE" value is always 0.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Reconnaissance Sampling

Waterbody Cover Sheet

Surveying Organization: JFNew

Waterbody Name: Holem Lake

Lake ID:

County: Marshall

Date: August 6, 2004

Habitat Stratum: IL

Ave. Lake Depth (ft): 9.7

Lake Level:

Crew Leader: S. Peel

GPS Metadata

Datum:	Zone:	Accuracy:
UTM NAD 1983	16	<2m

Recorder: S. Namestnik

Method: Trimble PRO XRS

Secchi Depth (ft): 2.8

Total # of Plant Beds Surveyed: 1

Total # of Species: 50

Littoral Zone Size (acres): 23.5

- ❑ Measured
- ✓ Estimated

Littoral Zone Max. Depth (ft): 8.4

- ❑ Measured
- ❑ Estimate (historical Secchi)
- ✓ Estimated (current Secchi)

Notable Conditions:

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew				**DATE: 8/6/04**
SITE INFORMATION				**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Holem Lake			Center of the Bed
Bed Size:				Latitude: 41°17'52"
Substrate: muck	Waterbody ID:			Longitude: 86°21'57"
Marl?	Total # of Species: 50			Max. Lakeward Extent of Bed
High Organic? Yes	**CanopyAbundance at Site**			Latitude: NA
	S: 3	N: 2	F: 3	E: 3	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID	
ACESAI	1				
ALISUB	1				
ASCINC	1				
BIDCOM	1				
BOECYC	1				
BRASCH	1				
CERDEM	3				
CHASP	2				
DECVER	2				
DRYTHP	1				
ELESP	1				
EUPPER	1				
FILALG	2				
HETDUB	1				
IMPCAP	1				
JUGNIG	1				
LEEORY	1				
LEMMIO	1				
LEMTRI	1				
LYTSAL	3				
MYRSPI	2				
NUPADV	2				

Individual Plant Bed Survey

Comments: "QE" is always 0.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or
letter to denote specific
location of a species;
referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew	**DATE: 8/6/04**

SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Holem Lake				Center of the Bed
Bed Size:					Latitude: 41°17'52"
Substrate: muck	Waterbody ID:				Longitude: 86°21'57"
Marl?	Total # of Species: 50				Max. Lakeward Extent of Bed
High Organic? Yes	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 2	F: 3	E: 3	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
NYMTUB	3			
PHAARU	1			
PHRAUS	1			
PELVIR	1			
POLHYS	1			
POLPER	1			
POLPUN	1			
PONCOR	1			
POPDEL	1			
POTILL	1			
POTNOD	1			
POTPUS	1			
RHUVER	1			
ROSPAL	1			
SAGLAT	1			
SALSP	2			
SCIACU	1			
SCIVAL	1			
SOLDUL	1			
SPIPOL	1			
TYPANG	2			
TYPGLA	1			

Individual Plant Bed Survey

Comments: "QE" is always 0.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or
letter to denote specific
location of a species;
referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: 8/6/04**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Holem Lake				Center of the Bed
Bed Size:					Latitude: 41°17'52"
Substrate: muck	Waterbody ID:				Longitude: 86°21'57"
Marl?	Total # of Species: 50				Max. Lakeward Extent of Bed
High Organic? Yes	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 2	F: 3	E: 3	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
TYPLAT	2			
ULMAME	1			
UTRGIB	1			
UTRVUL	1			
VIBSP	1			
WOLCOL	2			

Individual Plant Bed Survey

Comments: "QE" is always 0.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Reconnaissance Sampling

Waterbody Cover Sheet

Surveying Organization:	JFNew
Waterbody Name:	Kreighbaum Lake
Lake ID:	
County:	Marshall
Date:	August 6, 2004
Habitat Stratum:	IL
Ave. Lake Depth (ft):	10.9
Lake Level:	
Crew Leader:	S. Peel
Recorder:	S. Namestnik

GPS Metadata

Datum:	Zone:	Accuracy:
UTM NAD 1983	16	<2m

Method: Trimble PRO XRS

Secchi Depth (ft):	5.5
Total # of Plant Beds Surveyed:	1
Total # of Species:	38

Littoral Zone Size (acres): 31.6

- ❑ Measured
- ✓ Estimated

Littoral Zone Max. Depth (ft): 16.5

- ❑ Measured
- ❑ Estimate (historical Secchi)
- ✓ Estimated (current Secchi)

Notable Conditions:

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: 8/6/04**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Kreighbaum Lake				Center of the Bed
Bed Size:					Latitude: 41°18'07"
Substrate: muck	Waterbody ID:				Longitude: 86°23'08"
Marl?	Total # of Species: 38				Max. Lakeward Extent of Bed
High Organic? Yes	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 2	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID	
BIDCER	1				
CERDEM	3				
CHASP	1				
CXSP	1				
CYPESC	1				
DECVER	2				
FILALG	1				
LEMMIO	1				
LEMTRI	1				
LYTSAL	2				
MYREXA	1		1		
MYRSPI	3		1		
NAJGUA	1				
NUPADV	2				
NYMTUB	2				
PELVIR	2				
POLPER	1				
PONCOR	1				
POTAMP	1				
POTCRI	2				
POTFOL	1				
POTGRA	1				

Individual Plant Bed Survey

Comments: "QE" code is always 0.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew	**DATE: 8/6/04**

SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Kreighbaum Lake				Center of the Bed
Bed Size:					Latitude: 41°18'07"
Substrate: muck	Waterbody ID:				Longitude: 86°23'08"
Marl?	Total # of Species: 38				Max. Lakeward Extent of Bed
High Organic? Yes	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 2	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
POTILL	2			
POTNAT	1			
POTPEC	1			
POTPUS	1			
POTZOS	1			
RHUVER	1			
SCIACU	1			
SCIPUN	1			
SCISUB	1			
SPIPOL	1			
TYPANG	1			
TYPGLA	1			
TYPLAT	2			
UTRCIB	1			
UTRVUL	1			
WOLCOL	2			

Individual Plant Bed Survey

Comments: "QE" code is always 0.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
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E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Reconnaissance Sampling

<u>Waterbody Cover Sheet</u>

Surveying Organization: JFNew

Waterbody Name: Millpond Lake

Lake ID:

County: Marshall

Date: August 6, 2004

Habitat Stratum: IL

Ave. Lake Depth (ft): 4.5

Lake Level:

GPS Metadata

Datum:	Zone:	Accuracy:
UTM NAD 1983	16	<2m

Crew Leader: S. Peel

Recorder: S. Namestnik

Method: Trimble PRO XRS

Secchi Depth (ft): 6.8

Total # of Plant Beds Surveyed: 1

Total # of Species: 38

Littoral Zone Size (acres): 121.3

☐ Measured

✓ Estimated

Littoral Zone Max. Depth (ft): 20.4

☐ Measured

☐ Estimate (historical Secchi)

✓ Estimated (current Secchi)

Notable Conditions:

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: 8/6/04**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Millpond Lake				Center of the Bed
Bed Size:					Latitude: 41°17'53"
Substrate: muck	Waterbody ID:				Longitude: 86°23'22"
Marl?	Total # of Species: 38				Max. Lakeward Extent of Bed
High Organic? Yes	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 3	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
CEPOCC	1			
CERDEM	3			
CHASP	1			
CYP SP	1			
DECVER	2			
ELOCAN	1			
FILALG	2			
IMPCAP	1			
IRIVIS	1			
LEMMIO	1			
LEMTRI	1			
LYTSAL	2			
MYRSPI	3			
NAJGUA	1			
NUPADV	3			
NYMTUB	2			
PELVIR	1			
POLHYS	1			
POLLAP	1			
PONCOR	1			
POTAMP	2			
POTCRI	1			

Individual Plant Bed Survey

Comments: "QE" code is always 0.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: 8/6/04**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Millpond Lake				Center of the Bed
Bed Size:					Latitude: 41°17'53"
Substrate: muck	Waterbody ID:				Longitude: 86°23'22"
Marl?	Total # of Species: 38				Max. Lakeward Extent of Bed
High Organic? Yes	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 3	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
POTFOL	1			
POTILL	2			
POTNOD	1			
POTPEC	1			
POTPUS	2		1	
POTZOS	1			
RHUVER	1			
SAGLAT	1			
SAL SP	1			
SPIPOL	2			
TYPANG	1			
TYPGLA	1			
TYPLAT	2			
UTRGIB	2			
UTRVUL	3			
WOLCOL	3			

Individual Plant Bed Survey

Comments: "QE" code is always 0.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifiec

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

APPENDIX E:

AERIAL PHOTOGRAPHS
COOK, HOLEM, KREIGHBAUM, AND MILLPOND LAKES
1998 AND 2003

FOUR LAKES WATERSHED DIAGNOSTIC STUDY
MARSHALL COUNTY, INDIANA

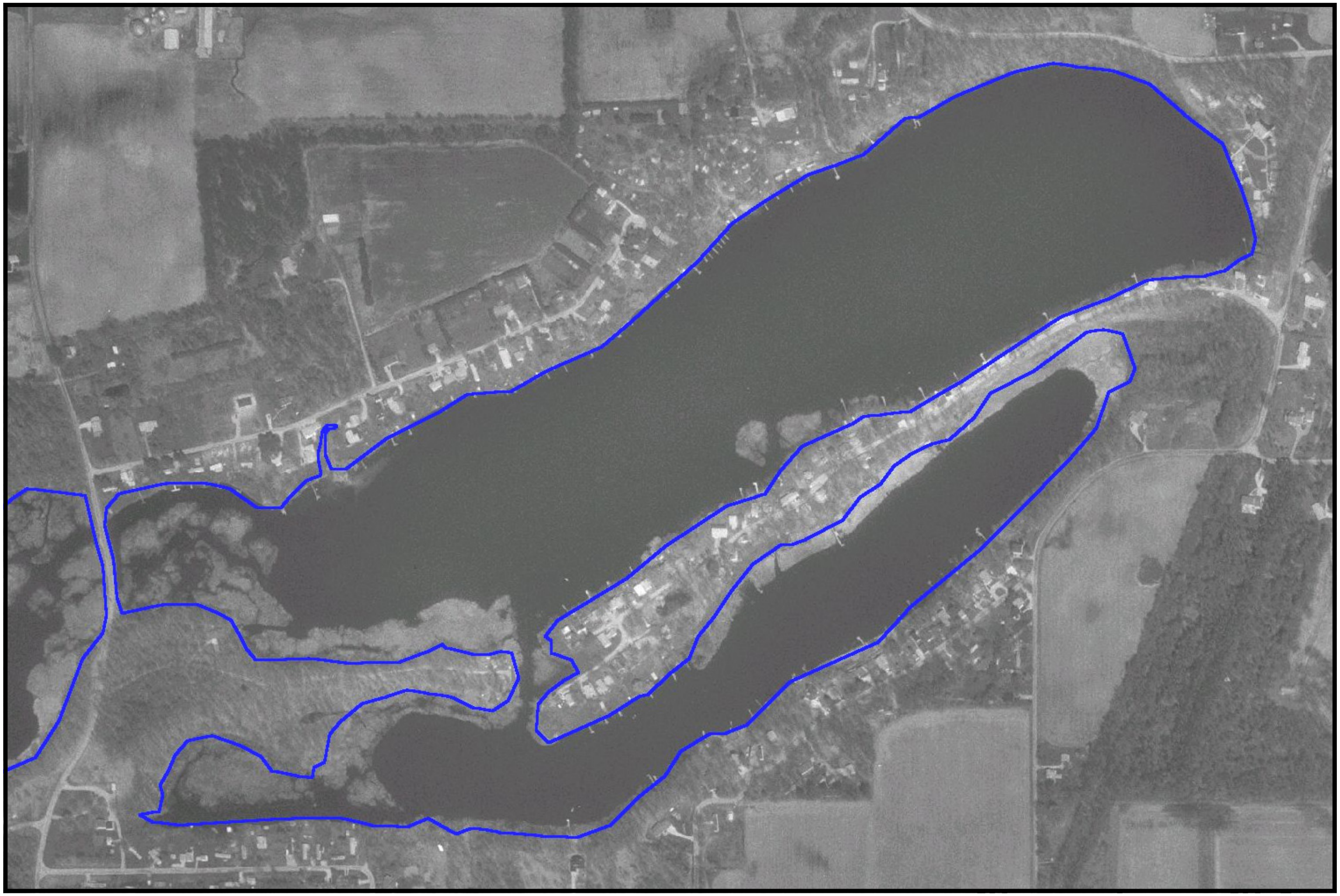

Figure E1: Cook and Holem Lakes
1998 Aerial Photograph
Marshall County, Indiana

N

JFNew # 02-10-37

JFNew
708 Roosevelt Road, Walkerton, IN 46574
Phone 574-586-3400 / Fax 574-586-3446
www.jfnew.com

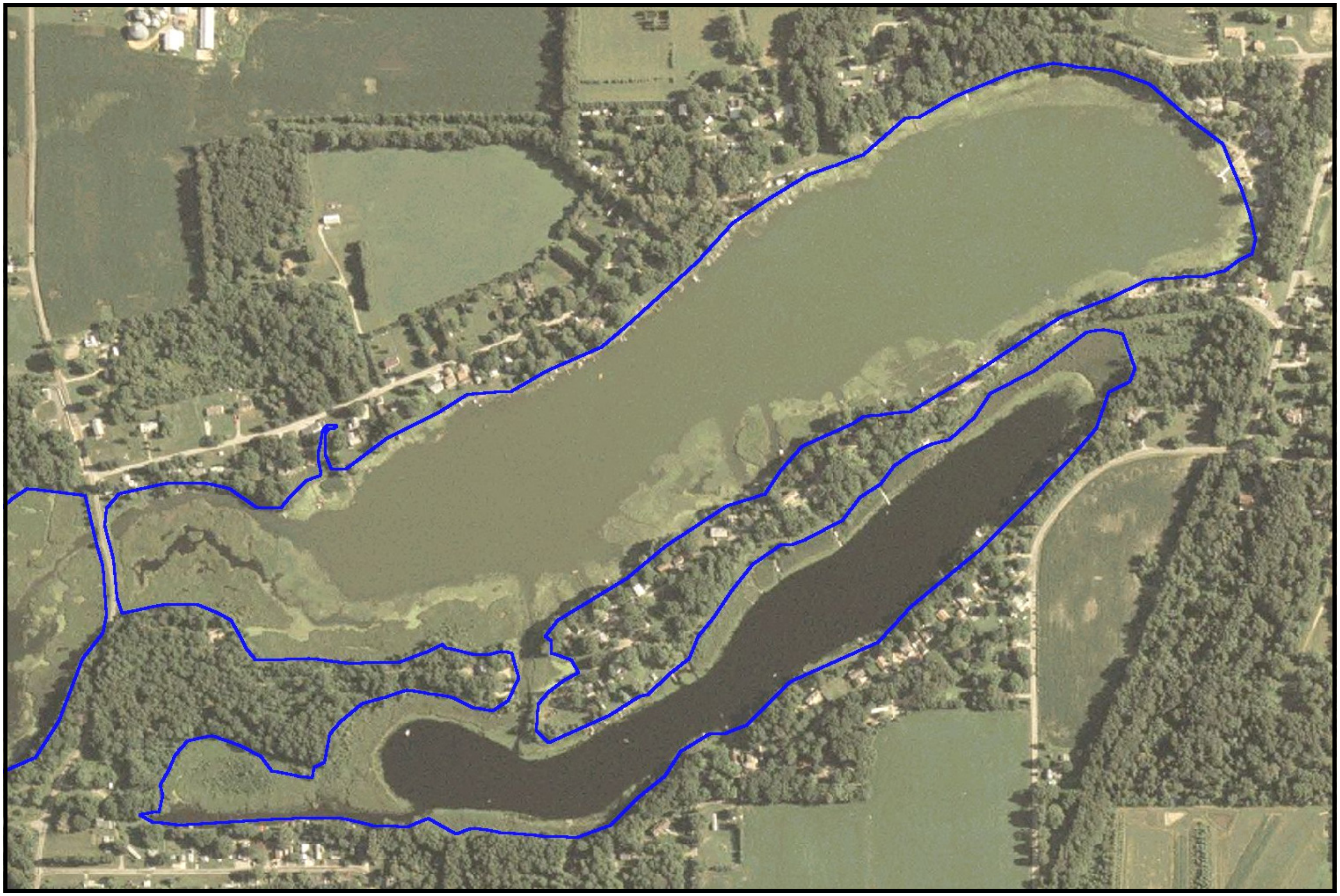

Figure E2: Cook and Holem Lakes
2003 Aerial Photograph
Marshall County, Indiana

N

JFNew # 02-10-37

JFNew
708 Roosevelt Road, Walkerton, IN 46574
Phone 574-586-3400 / Fax 574-586-3446
www.jfnew.com

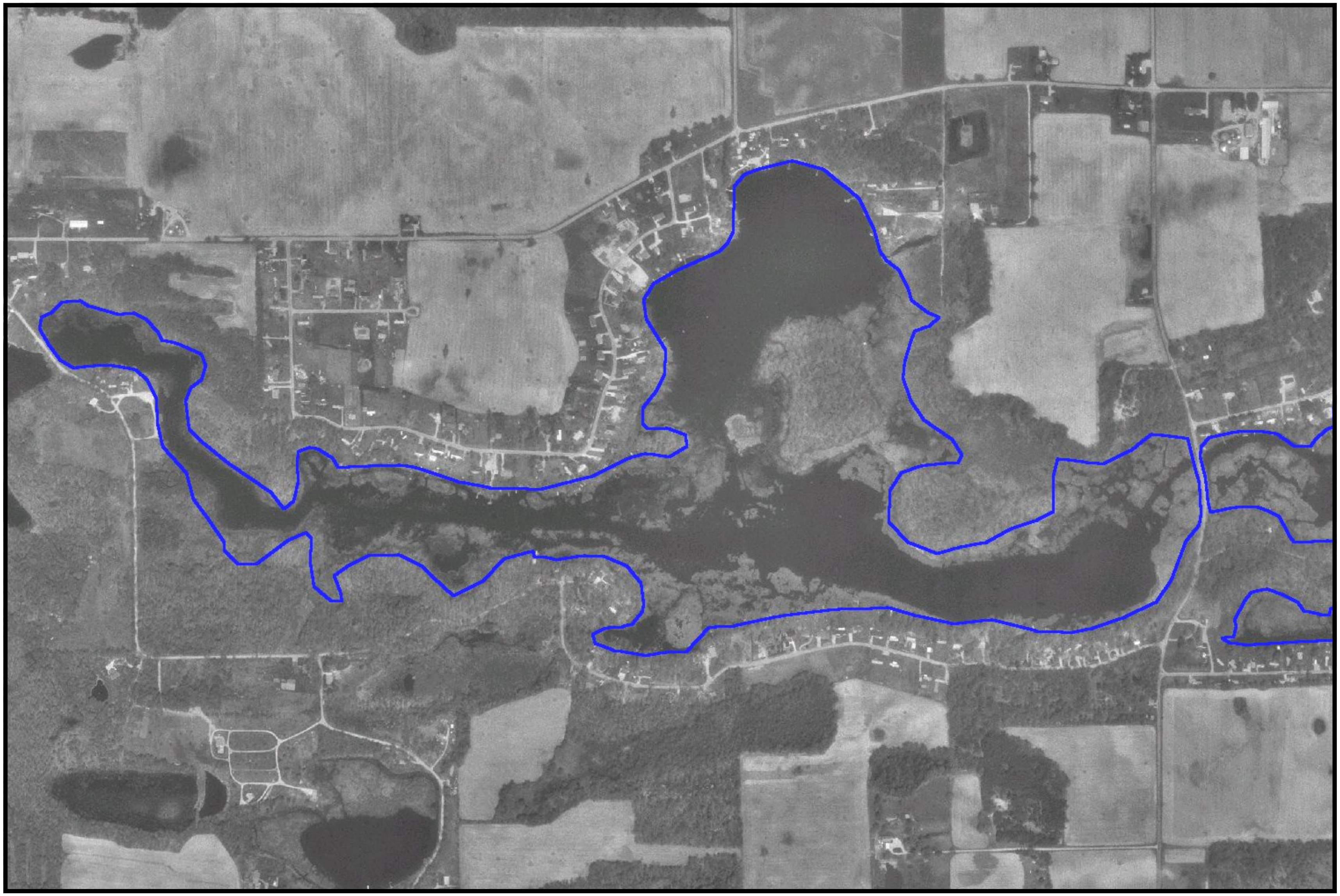

Figure E3: Kreighbaum and Millpond Lakes
1998 Aerial Photograph
Marshall County, Indiana

N

JFNew # 02-10-37

JFNew
708 Roosevelt Road, Walkerton, IN 46574
Phone 574-586-3400 / Fax 574-586-3446
www.jfnew.com

Figure E4: Kreighbaum and Millpond Lakes
2003 Aerial Photograph
Marshall County, Indiana

N

JFNew # 02-10-37

JFNew
708 Roosevelt Road, Walkerton, IN 46574
Phone 574-586-3400 / Fax 574-586-3446
www.jfnew.com

APPENDIX F:

WATER BUDGET
COOK, HOLEM, KREIGHBAUM, AND MILLPOND LAKES

FOUR LAKES WATERSHED DIAGNOSTIC STUDY
MARSHALL COUNTY, INDIANA

Appendix F. Water Budget Calculation: Cook, Holem, Kreighbaum, and Millpond Lakes.

Table F1. Water budget calculations for Cook Lake.

Watershed	**Cook Lake**
Watershed size (ac)	1,520
Mean Watershed Runoff (ac-ft/yr)	1,573
Lake Volume (ac-ft)	1,647
Closest gauged stream	Yellow River at Plymouth
Stream watershed (mi2)	294
Stream watershed (acres)	188,160
Mean annual Q (cfs)	269
Mean annual Q (ac-ft/yr)	194,747
Mean ppt (in/yr)	36.78
Mean watershed ppt (ac-ft/yr)	576,710
Watershed C	0.33769
Pan evaporation (in/yr)	28.05
Pan evaporation coefficient	0.70
Lake Surface Area (acres)	95
Estimated lake evaporation (ac-ft)	156
Direct precipitation to lake (ac-ft)	292
Water Budget Summary	
Direct precipitation to lake (ac-ft)	292
Runoff from watershed (ac-ft)	1,573
Discharge from Holem (ac-ft)	280
Evaporation (ac-ft)	156
TOTAL LAKE OUTPUT (ac-ft)	1,989
Hydraulic Residence Time (yr)	0.83
Watershed Area:Lake Area	15.9

Table F2. Water budget calculations for Holem Lake.

Watershed	**Holem Lake**
Watershed size (ac)	217
Mean Watershed Runoff (ac-ft/yr)	224
Lake Volume (ac-ft)	387
Closest gauged stream	Yellow River at Plymouth
Stream watershed (mi2)	294
Stream watershed (acres)	188,160
Mean annual Q (cfs)	269
Mean annual Q (ac-ft/yr)	194,747
Mean ppt (in/yr)	36.78
Mean watershed ppt (ac-ft/yr)	576,710
Watershed C	0.338
Pan evaporation (in/yr)	28.05
Pan evaporation coefficient	0.70
Lake Surface Area (acres)	39
Estimated lake evaporation (ac-ft)	64
Direct precipitation to lake (ac-ft)	120
Water Budget Summary	
Direct precipitation to lake (ac-ft)	120
Runoff from watershed (ac-ft)	224
Evaporation (ac-ft)	64
TOTAL LAKE OUTPUT (ac-ft)	280
Hydraulic Residence Time (yr)	1.38
Watershed Area:Lake Area	5.6

Table F3. Water budget calculations for Kreighbaum Lake.

Watershed	**Kreighbaum Lake**
Watershed size (ac)	464
Mean Watershed Runoff (ac-ft/yr)	481
Lake Volume (ac-ft)	425
Closest gauged stream	Yellow River at Plymouth
Stream watershed (mi2)	294
Stream watershed (acres)	188,160
Mean annual Q (cfs)	269
Mean annual Q (ac-ft/yr)	194,747
Mean ppt (in/yr)	36.78
Mean watershed ppt (ac-ft/yr)	576,710
Watershed C	0.338
Pan evaporation (in/yr)	28.05
Pan evaporation coefficient	0.70
Lake Surface Area (acres)	39
Estimated lake evaporation (ac-ft)	64
Direct precipitation to lake (ac-ft)	120
Water Budget Summary	
Direct precipitation to lake (ac-ft)	120
Runoff from watershed (ac-ft)	481
Evaporation (ac-ft)	64
TOTAL LAKE OUTPUT (ac-ft)	536
Hydraulic Residence Time (yr)	0.79
Watershed Area:Lake Area	11.9

Table F4. Water budget calculations for Millpond Lake.

Watershed	Mill Pond
Direct Watershed size (ac)	661
Mean Watershed Runoff (ac-ft/yr)	685
Lake Volume (ac-ft)	578
Closest gauged stream	Yellow River at Plymouth
Stream watershed (mi2)	294
Stream watershed (acres)	188,160
Mean annual Q (cfs)	269
Mean annual Q (ac-ft/yr)	194,747
Mean ppt (in/yr)	36.78
Mean watershed ppt (ac-ft/yr)	576,710
Watershed C	0.33769
Pan evaporation (in/yr)	28.05
Pan evaporation coefficient	0.70
Lake Surface Area (acres)	126
Estimated lake evaporation (ac-ft)	206
Direct precipitation to lake (ac-ft)	386
Water Budget Summary	
Direct precipitation to lake (ac-ft)	386
Runoff from watershed (ac-ft)	685
Discharge from Cook (ac-ft)	1,989
Discharge from Kreighbaum (ac-ft)	536
Evaporation (ac-ft)	206
TOTAL LAKE OUTPUT (ac-ft)	3,390
Hydraulic Residence Time (yr)	0.2
Total Watershed Area:Lake Area	22.7

APPENDIX G:

PHOSPHORUS MODEL
COOK, HOLEM, KREIGHBAUM, AND MILLPOND LAKES

FOUR LAKES WATERSHED DIAGNOSTIC STUDY
MARSHALL COUNTY, INDIANA

Appendix G. Phosphorus modeling for Cook, Holem, Kreighbaum, and Millpond Lakes.

Table G1. Phosphorus model for Cook Lake completed November 8, 2004.

Phosphorus Loading - Lake Response Model				
INPUT DATA		**Unit**		
Area, Lake	84	acres		
Volume, Lake	1600	ac-ft		
Mean Depth	19.0	ft		
Hydraulic Residence Time	0.82			
Flushing Rate	1.22	1/yr		
Mean Annual Precipitation	0.90	m		
[P] in precipitation	0.03	mg/l		
[P] in epilimnion	0.038	mg/l		
[P] in hypolimnion	0.413	mg/l		
Volume of epilimnion	1080	ac-ft		
Volume of hypolimnion	567	ac-ft		
Land Use (in watershed)	**Area**	--------	**P-export Coefficient**	
Deciduous Forest	104.5	hectare	0.2	kg/ha-yr
Emergent Herbaceous Wetlands	11.7	hectare	0.1	kg/ha-yr
Evergreen Forest	1.3	hectare	0.15	kg/ha-yr
High Intensity Residential	1.3	hectare	2.5	kg/ha-yr
High Intensity:Commercial/Ind	1.1	hectare	2.5	kg/ha-yr
Low Intensity Residential	50.1	hectare	0.8	kg/ha-yr
Mixed Forest	0.0	hectare	0.175	kg/ha-yr
Pasture/Hay	107.9	hectare	0.6	kg/ha-yr
Row Crops	233.8	hectare	1.5	kg/ha-yr
Woody Wetlands	8.2	hectare	0.1	kg/ha-yr
Septic Systems	--------	-------	0.50	kg/ha-yr
	520.01			
Other Data				
Soil Retention coefficient	0.75	-------		
# Permanent Homes	77	homes		
Use of Permanent Homes	1.0	year		
# Seasonal Homes	20	homes		
Use of Seasonal Homes	0.50	year		
# Seasonal Homes	5	homes		
Use of Seasonal Homes	0.25	year		
Avg. Persons Per Home	3	persons		
OUTPUT DATA				
P load from watershed	484.6	kg/yr		
P load from precipitation	9.20	kg/yr		
P load from septic systems	33.09	kg/yr		
P load from Holem Lake	30.4	kg/yr		
Total External P load	557.31	kg/yr		
Areal P loading	1.639	g/m2-yr		
Predicted P from Vollenweider	0.096	mg/l		
Back Calculated L total	2.854	g/m2-yr		
Estimation of L internal	1.215	g/m2-yr		
% of External Loading	57.4	%		
% of Internal Loading	42.6	%		

Table G2. Phosphorus model for Holem Lake completed November 8, 2004.

Phosphorus Loading - Lake Response Model				
INPUT DATA		**Unit**		
Area, Lake	39	acres		
Volume, Lake	387	ac-ft		
Mean Depth	9.9	ft		
Hydraulic Residence Time	1.38			
Flushing Rate	0.72	1/yr		
Mean Annual Precipitation	0.90	m		
[P] in precipitation	0.03	mg/l		
[P] in epilimnion	0.047	mg/l		
[P] in hypolimnion	0.199	mg/l		
Volume of epilimnion	282	ac-ft		
Volume of hypolimnion	105	ac-ft		
Land Use (in watershed)	**Area**	--------	**P-export Coefficient**	
Deciduous Forest	17.2	hectare	0.2	kg/ha-yr
Emergent Herbaceous Wetlands	2.9	hectare	0.1	kg/ha-yr
Evergreen Forest	3.3	hectare	0.15	kg/ha-yr
High Intensity Residential	0.0	hectare	2.5	kg/ha-yr
High Intensity:Commercial/Ind	0.1	hectare	2.5	kg/ha-yr
Low Intensity Residential	17.3	hectare	0.8	kg/ha-yr
Mixed Forest	0.4	hectare	0.175	kg/ha-yr
Pasture/Hay	3.2	hectare	0.6	kg/ha-yr
Row Crops	32.6	hectare	1.5	kg/ha-yr
Woody Wetlands	0.0	hectare	0.1	kg/ha-yr
Septic Systems	--------	--------	0.50	kg/ha-yr
	76.93			
Other Data				
Soil Retention coefficient	0.75	--------		
# Permanent Homes	46	homes		
Use of Permanent Homes	1.0	year		
# Seasonal Homes	12	homes		
Use of Seasonal Homes	0.50	year		
# Seasonal Homes	3	homes		
Use of Seasonal Homes	0.25	year		
Avg. Persons Per Home	3	persons		
OUTPUT DATA				
P load from watershed	69.1	kg/yr		
P load from precipitation	4.27	kg/yr		
P load from septic systems	19.78	kg/yr		
Total External P load	93.20	kg/yr		
Areal P loading	0.590	g/m2-yr		
Predicted P from Vollenweider	0.048	mg/l		
Back Calculated L total	1.076	g/m2-yr		
Estimation of L internal	0.485	g/m2-yr		
% of External Loading	54.9	%		
% of Internal Loading	45.1	%		

Table G3. Phosphorus model for Kreighbaum Lake completed November 8, 2004.

Phosphorus Loading - Lake Response Model				
INPUT DATA		**Unit**		
Area, Lake	39	acres		
Volume, Lake	425	ac-ft		
Mean Depth	10.9	ft		
Hydraulic Residence Time	0.79			
Flushing Rate	1.27	1/yr		
Mean Annual Precipitation	0.90	m		
[P] in precipitation	0.03	mg/l		
[P] in epilimnion	0.037	mg/l		
[P] in hypolimnion	0.382	mg/l		
Volume of epilimnion	371	ac-ft		
Volume of hypolimnion	54	ac-ft		
Land Use (in watershed)	**Area**	**--------**	**P-export Coefficient**	
Deciduous Forest	24.3	hectare	0.2	kg/ha-yr
Emergent Herbaceous Wetlands	3.7	hectare	0.1	kg/ha-yr
Evergreen Forest	2.8	hectare	0.15	kg/ha-yr
High Intensity Residential	0.2	hectare	2.5	kg/ha-yr
High Intensity:Commercial/Ind	0.0	hectare	2.5	kg/ha-yr
Low Intensity Residential	11.8	hectare	0.8	kg/ha-yr
Mixed Forest	0.0	hectare	0.175	kg/ha-yr
Pasture/Hay	31.6	hectare	0.6	kg/ha-yr
Row Crops	96.1	hectare	1.5	kg/ha-yr
Woody Wetlands	2.6	hectare	0.1	kg/ha-yr
Septic Systems	--------	--------	0.50	kg/ha-yr
	173.07			
Other Data				
Soil Retention coefficient	0.75	--------		
# Permanent Homes	32	homes		
Use of Permanent Homes	1.0	year		
# Seasonal Homes	8	homes		
Use of Seasonal Homes	0.50	year		
# Seasonal Homes	2	homes		
Use of Seasonal Homes	0.25	year		
Avg. Persons Per Home	3	persons		
OUTPUT DATA				
P load from watershed	178.9	kg/yr		
P load from precipitation	4.27	kg/yr		
P load from septic systems	13.69	kg/yr		
Total External P load	196.91	kg/yr		
Areal P loading	1.248	g/m2-yr		
Predicted P from Vollenweider	0.088	mg/l		
Back Calculated L total	1.148	g/m2-yr		
Estimation of L internal	-0.099	g/m2-yr		
% of External Loading	108.7	%		
% of Internal Loading	-8.7	%		

Table G4. Phosphorus model for Millpond Lake completed November 8, 2004.

Phosphorus Loading - Lake Response Model				
INPUT DATA		**Unit**		
Area, Lake	126	acres		
Volume, Lake	578	ac-ft		
Mean Depth	4.6	ft		
Hydraulic Residence Time	0.20			
Flushing Rate	5.00	1/yr		
Mean Annual Precipitation	0.90	m		
[P] in precipitation	0.03	mg/l		
[P] in epilimnion	0.061	mg/l		
[P] in hypolimnion	0.044	mg/l		
Volume of epilimnion	289	ac-ft		
Volume of hypolimnion	289	ac-ft		
Land Use (in watershed)	**Area**	--------	**P-export Coefficient**	
Deciduous Forest	64.0	hectare	0.2	kg/ha-yr
Emergent Herbaceous Wetlands	13.8	hectare	0.1	kg/ha-yr
Evergreen Forest	1.0	hectare	0.15	kg/ha-yr
High Intensity Residential	0.1	hectare	2.5	kg/ha-yr
Low Intensity Residential	31.4	hectare	0.8	kg/ha-yr
Mixed Forest	0.1	hectare	0.175	kg/ha-yr
Pasture/Hay	35.6	hectare	0.6	kg/ha-yr
Row Crops	68.2	hectare	1.5	kg/ha-yr
Woody Wetlands	7.3	hectare	0.1	
Septic Systems		--------	0.50	kg/ha-yr
	267.77			
Other Data				
Soil Retention coefficient	0.75	--------		
# Permanent Homes	52	homes		
Use of Permanent Homes	1.0	year		
# Seasonal Homes	14	homes		
Use of Seasonal Homes	0.50	year		
# Seasonal Homes	3	homes		
Use of Seasonal Homes	0.25	year		
Avg. Persons Per Home	3	persons		
OUTPUT DATA				
P load from watershed	164.1	kg/yr		
P load from precipitation	13.80	kg/yr		
P load from septic systems	22.41	kg/yr		
P load from Cook Lake	409.7	kg/yr		
P load from Kreighbaum Lake	53.6	kg/yr		
Total External P load	663.61	kg/yr		
Areal P loading	1.301	g/m2-yr		
Predicted P from Vollenweider	0.072	mg/l		
Back Calculated L total	0.892	g/m2-yr		
Estimation of L internal	-0.409	g/m2-yr		
% of External Loading	145.9	%		
% of Internal Loading	-45.9	%		

APPENDIX H:

POTENTIAL FUNDING SOURCES

FOUR LAKES WATERSHED DIAGNOSTIC STUDY
MARSHALL COUNTY, INDIANA

Appendix H. Potential Funding Sources.

There are several cost-share grants available from both state and federal government agencies specific to watershed management. Community groups and/or Soil and Water Conservation Districts can apply for the majority of these grants. The main goal of these grants and other funding sources is to improve water quality though the use of specific BMPs. As public awareness shifts towards watershed management, these grants will become more and more competitive. Therefore, any association interested in improving water quality through the use of grants must become active soon. Once an association is recognized as a "watershed management activist" it will become easier to obtain these funds repeatedly. The following are some of the possible major funding sources available to lake and watershed associations for watershed management.

Lake and River Enhancement Program (LARE)
LARE is administered by the Indiana Department of Natural Resources, Division of Soil Conservation. The program's main goals are to control sediment and nutrient inputs to lakes and streams and prevent or reverse degradation from these inputs through the implementation of corrective measures. Under present policy, the LARE program may fund lake and watershed specific construction actions up to $100,000 for a single project or $300,000 for all projects on a lake or stream. The LARE program also provides a maximum of $100,000 for the removal of sediment from a particular site on a lake and a cumulative total of $300,000 for all sediment removal projects on a lake. An approved sediment removal plan must be on file with the LARE office for projects to receive sediment removal funding. Finally, the LARE program will provide $100,000 for a one-time whole lake treatment to control aggressive, invasive aquatic plants. A cumulative total of $20,000 over a three year period may be obtained for additional spot treatment following the whole lake treatment. As with the sediment removal funding, an approved aquatic plant management plan must be on file with the LARE office for the lake association to receive funding. All approved projects require a 0 to 25% cash or in-kind match, depending on the project. LARE also has a "watershed land treatment" component that can provide grants to SWCDs for multi-year projects. The funds are available on a cost-sharing basis with landowners who implement various BMPs. All of the LARE programs are recommended as a project funding source for the Four Lakes watershed. More information about the LARE program can be found at http://www.in.gov/dnr/soilcons/programs/lare.

Clean Water Act Section 319 Nonpoint Source Pollution Management Grant
The 319 Grant Program is administered by the Indiana Department of Environmental Management (IDEM), Office of Water Management, Watershed Management Section. 319 is a federal grant made available by the Environmental Protection Agency (EPA). 319 grants fund projects that target nonpoint source water pollution. Nonpoint source pollution (NPS) refers to pollution originating from general sources rather than specific discharge points (Olem and Flock, 1990). Sediment, animal and human waste, nutrients, pesticides, and other chemicals resulting from land use activities such as mining, farming, logging, construction, and septic fields are considered NPS pollution. According to the EPA, NPS pollution is the number one contributor to water pollution in the United States. To qualify for funding, the water body must meet specific criteria such as being listed in the state's 305(b) report as a high priority water body or be identified by a diagnostic study as being impacted by NPS pollution. Funds can be requested

for up to $300,000 for individual projects. There is a 25% cash or in-kind match requirement. To qualify for implementation projects, there must be a watershed management plan for the receiving waterbody. This plan must meet all of the current 319 requirements. This diagnostic study serves as an n excellent foundation for developing a watershed management plan since it satisfies several, but not all, of the 319 requirements for a watershed management plan. More information about the Section 319 program can be obtained from http://www.in.gov/idem/water/planbr/wsm/319main.html.

Section 104(b)(3) NPDES Related State Program Grants
Section 104(b)(3) of the Clean Water Act gives authority to a grant program called the National Pollutant Discharge Elimination System (NPDES) Related State Program Grants. These grants provide money for developing, implementing, and demonstrating new concepts or requirements that will improve the effectiveness of the NPDES permit program that regulates point source discharges of water pollution. Projects that qualify for Section 104(b)(3) grants involve water pollution sources and activities regulated by the NPDES program. The awarded amount can vary by project and there is a required 5% match. For more information on Section 104(b)(3) grants, please see the IDEM website at: http://www.in.gov/idem/water/planbr/wsm/104main.html.

Section 205(j) Water Quality Management Planning Grants
Funds allocated by Section 205(j) of the Clean Water Act are granted for water quality management planning and design. Grants are given to municipal governments, county governments, regional planning commissions, and other public organizations for researching point and non-point source pollution problems and developing plans to deal with the problems. According to the IDEM Office of Water Quality website: "The Section 205(j) program provides for projects that gather and map information on non-point and point source water pollution, develop recommendations for increasing the involvement of environmental and civic organizations in watershed planning and implementation activities, and implement watershed management plans. No match is required. For more information on and 205(j) grants, please see the IDEM website at: http://www.in.gov/idem/water/planbr/wsm/205jmain.html.

Other Federal Grant Programs
The USDA and EPA award research and project initiation grants through the U.S. National Research Initiative Competitive Grants Program and the Agriculture in Concert with the Environment Program.

Watershed Protection and Flood Prevention Program
The Watershed Protection and Flood Prevention Program is funded by the U.S. Department of Agriculture and is administered by the Natural Resources Conservation Service. Funding targets a variety of watershed activities including watershed protection, flood prevention, erosion and sediment control, water supply, water quality, fish and wildlife habitat enhancement, wetlands creation and restoration, and public recreation in small watersheds (250,000 or fewer acres). The program covers 100% of flood prevention construction costs or 50% of construction costs for agricultural water management, recreational, or fish and wildlife projects.

Conservation Reserve Program

The Conservation Reserve Program (CRP) is funded by the USDA and administered by the Farm Service Agency (FSA). CRP is a voluntary, competitive program designed to encourage farmers to establish vegetation on their property in an effort to decrease erosion, improve water quality, or enhance wildlife habitat. The program targets farmed areas that have a high potential for degrading water quality under traditional agricultural practices or areas that might make good wildlife habitat if they were not farmed. Such areas include highly erodible land, riparian zones, and farmed wetlands. Currently, the program offers continuous sign-up for practices like grassed waterways and filter strips. Participants in the program receive cost share assistance for any plantings or construction as well as annual payments for any land set aside.

Wetlands Reserve Program

The Wetlands Reserve Program (WRP) is funded by the USDA and is administered by the NRCS. WRP is a subsection of the Conservation Reserve Program. This voluntary program provides funding for the restoration of wetlands on agricultural land. To qualify for the program, land must be restorable and suitable for wildlife benefits. This includes farmed wetlands, prior converted cropland, farmed wet pasture, farmland that has become a wetland as a result of flooding, riparian areas which link protected wetlands, and the land adjacent to protected wetlands that contribute to wetland functions and values. Landowners may place permanent or 30-year easements on land in the program. Landowners receive payment for these easement agreements. Restoration cost-share funds are also available. No match is required.

Grassland Reserve Program

The Grassland Reserve Program (GRP) is funded by the USDA and is administered by the NRCS. GRP is a voluntary program that provides funding the restoration or improvement of natural grasslands, rangelands, prairies or pastures. To qualify for the program the land must consist of at least a 40 acre contiguous tract of land, be restorable, and provide water quality or wildlife benefit. Landowners may enroll land in the Grassland Reserve Program for 10, 15, 20, or 30 years or enter their land into a 30-year permanent easement. Landowners receive payment of up to 75% of the annual grazing value. Restoration cost-share funds of up to 75% for restored or 90% for virgin grasslands are also available.

Community Forestry Grant Program

The U.S. Forest Service through the Indiana Department of Natural Resources Division of Forestry provides three forms of funding for communities under the Community Forestry Grant Program. Urban Forest Conservation Grants (UFCG) are designed to help communities develop long term programs to manage their urban forests. UFCG funds are provided to communities to improve and protect trees and other natural resources; projects that target program development, planning, and education are emphasized. Local municipalities, not-for-profit organizations, and state agencies can apply for $2,000-20,000 annually. The second type of Community Forestry Grant Program, the Arbor Day Grant Program, funds activities which promote Arbor Day efforts and the planting and care of urban trees. $500-1000 grants are generally awarded. The Tree Steward Program is an educational training program that involves six training sessions of three hours each. The program can be offered in any county in Indiana and covers a variety of tree care and planting topics. Generally, $500-1000 is available to assist communities in starting a county or regional Tree Steward Program. Each of these grants requires an equal match.

Forest Land Enhancement Program (FLEP)
FLEP replaces the former Forestry Incentive Program. It provides financial, technical, and educational assistance to the Indiana Department of Natural Resources Division of Forestry to assist private landowners in forestry management. Projects are designed to enhance timber production, fish and wildlife habitat, soil and water quality, wetland and recreational resources, and aesthetic value. FLEP projects include implementation of practices to protect and restore forest lands, control invasive species, and preserve aesthetic quality. Projects may also include reforestation, afforestation, or agroforestry practices. The IDNR Division of Forestry has not determined how they will implement this program; however, their website indicates that they are working to determine their implementation and funding procedures. More information can be found at http://www.in.gov/dnr/forestry.

Wildlife Habitat Incentive Program
The Wildlife Habitat Incentive Program (WHIP) is funded by the USDA and administered by the NRCS. This program provides support to landowners to develop and improve wildlife habitat on private lands. Support includes technical assistance as well cost sharing payments. Those lands already enrolled in WRP are not eligible for WHIP. The match is 25%.

Environmental Quality Incentives Program
The Environmental Quality Incentives Program (EQIP) is a voluntary program designed to provide assistance to producers to establish conservation practices in target areas where significant natural resource concerns exist. Eligible land includes cropland, rangeland, pasture, and forestland, and preference is given to applications which propose BMP installation that benefits wildlife. EQIP offers cost-share and technical assistance on tracts that are not eligible for continuous CRP enrollment. Certain BMPs receive up to 75% cost-share. In return, the producer agrees to withhold the land from production for five years. Practices that typically benefit wildlife include: grassed waterways, grass filter strips, conservation cover, tree planting, pasture and hay planting, and field borders. Best fertilizer and pesticide management practices, innovative approaches to enhance environmental investments like carbon sequestration or market-based credit trading, and groundwater and surface water conservation are also eligible for EQIP cost-share.

Small Watershed Rehabilitation Program
The Small Watershed Rehabilitation Program provides funding for rehabilitation of aging small watershed impoundments that have been constructed within the last 50 years. This program is newly funded through the 2002 Farm Bill and is currently under development. More information regarding this and other Farm Bill programs can be found at http://www.usda.gov/farmbill.

Farmland Protection Program
The Farmland Protection Program (FPP) provides funds to help purchase development rights in order to keep productive farmland in use. The goals of FPP are: to protect valuable, prime farmland from unruly urbanization and development; to preserve farmland for future generations; to support a way of life for rural communities; and to protect farmland for long-term food security.

Debt for Nature

Debt for Nature is a voluntary program that allows certain FSA borrowers to enter into 10-year, 30-year, or 50-year contracts to cancel a portion of their FSA debts in exchange for devoting eligible acreage to conservation, recreation, or wildlife practices. Eligible acreage includes: wetlands, highly erodible lands, streams and their riparian areas, endangered species or significant wildlife habitat, land in 100-year floodplains, areas of high water quality or scenic value, aquifer recharge zones, areas containing soil not suited for cultivation, and areas adjacent to or within administered conservation areas.

Partners for Fish and Wildlife Program

The Partners for Fish and Wildlife Program (PFWP) is funded and administered by the U.S. Department of the Interior through the U.S. Fish and Wildlife Service. The program provides technical and financial assistance to landowners interested in improving native habitat for fish and wildlife on their land. The program focuses on restoring wetlands, native grasslands, streams, riparian areas, and other habitats to natural conditions. The program requires a 10-year cooperative agreement and a 1:1 match.

North American Wetland Conservation Act Grant Program

The North American Wetland Conservation Act Grant Program (NAWCA) is funded and administered by the U.S. Department of Interior. This program provides support for projects that involve long-term conservation of wetland ecosystems and their inhabitants including waterfowl, migratory birds, fish, and other wildlife. The match for this program is on a 1:1 basis.

National Fish and Wildlife Foundation (NFWF)

The National Fish and Wildlife Foundation is administered by the U.S. Department of the Interior. The program promotes healthy fish and wildlife populations and supports efforts to invest in conservation and sustainable use of natural resources. The NFWF targets six priority areas which are wetland conservation, conservation education, fisheries, neotropical migratory bird conservation, conservation policy, and wildlife and habitat. The program requires a minimum of a 1:1 match. More information can be found at http://www.nfwf.org/about.htm.

Bring Back the Natives Grant Program

Bring Back the Natives Grant Program (BBNG) is a NFWF program that provides funds to restore damaged or degraded riverine habitats and the associated native aquatic species. Generally, BBNP supports on the ground habitat restoration projects that benefit native aquatic species within their historic range. Funding is jointly provided by a variety of federal organizations including the U.S. Fish and Wildlife Service, Bureau of Land Management, and U.S. Department of Agriculture and the National Fish and Wildlife Foundation. Typical projects include those that revise land management practices to remove the cause of habitat degradation, provide multiple specie benefit, include multiple project partners, and are innovative solutions that assist in the development of new technology. A 1:1 match is required; however, a 2:1 match is preferred. More information can be obtained from http://www.nfwf.org.

Native Plant Conservation Initiative

The Native Plant Conservation Initiative (NPCI) supplies funding for projects that protect, enhance, or restore native plant communities on public or private land. This NFWF program typically funds projects that protect and restore of natural resources, inform and educate the surrounding community, and assess current resources. The program provides nearly $450,000 in funding opportunities annually awarding grants ranging from $10,000-50,000 each. A 1:1 match is required for this grant. More information can be found at http://www.nfwf.org/programs/grant_apply.htm.

Freshwater Mussel Fund

The National Fish and Wildlife Foundation and the U.S. Fish and Wildlife Service fund the Freshwater Mussel Fund which provides funds to protect and enhance freshwater mussel resources. The program provides $100,000 in funding to approximately 5-10 applicants annually. More information can be found at http://www.nfwf.org/programs/grant_apply.htm.

Non-Profit Conservation Advocacy Group Grants

Various non-profit conservation advocacy groups provide funding for projects and land purchases that involve resource conservation. Ducks Unlimited and Pheasants Forever are two such organizations that dedicate millions of dollars per year to projects that promote and/or create wildlife habitat.

U.S. Environmental Protection Agency Environmental Education Program

The USEPA Environmental Education Program provides funding for state agencies, non-profit groups, schools, and universities to support environmental education programs and projects. The program grants nearly $200,000 for projects throughout Illinois, Indiana, Michigan, Minnesota, Wisconsin, and Ohio. More information is available at http://www.epa.gov/region5/ened/grants.html.

Core 4 Conservation Alliance Grants

Core 4 provides funding for public/private partnerships working toward Better Soil, Cleaner Water, Greater Profits and a Brighter Future. Partnerships must consist of agricultural producers or citizens teaming with government representatives, academic institutions, local associations, or area businesses. CTIC provides grants of up to $2,500 to facilitate organizational or business plan development, assist with listserve or website development, share alliance successes through CTIC publications and other national media outlets, provide Core 4 Conservation promotional materials, and develop speakers list for local and regional use. More information on Core 4 Conservation Alliance grants can be found at http://www.ctic.purdue.edu/CTIC/GrantApplication.pdf.

Indianapolis Power and Light Company (IPALCO) Golden Eagle Environmental Grant

The IPALCO Golden Eagle Grant awards grants of up to $10,000 to projects that seek improve, preserve, and protect the environment and natural resources in the state of Indiana. The award is granted to approximately 10 environmental education or restoration projects each year. Deadline for funding is typically in January. More information is available at http://www.ipalco.com/ABOUTIPALCO/Environment/Golden_Eagle.html

Nina Mason Pulliam Charitable Trust (NMPCT)
The NMPCT awards various dollar amounts to projects that help people in need, protect the environment, and enrich community life. Prioritization is given to projects in the greater Phoenix, AZ and Indianapolis, IN areas, with secondary priority being assigned to projects throughout Arizona and Indiana. The trust awarded nearly $20,000,000 in funds in the year 2000. More information is available at www.nmpct.org

Understanding Your Watershed:

- ★ The Four Lakes and their watershed lie in the Yellow River basin south of Plymouth, Indiana. Water from the lakes flows west and south to the Mississippi River.
- ★ The Four Lakes' watershed encompasses approximately 2,865 acres in Marshall County. Approximately 9.5 acres of land in the watershed drain to each acre of open water. (Watershed to lake ratio = 9.5:1)
- ★ Holem Lake possesses the smallest ratio (5.5:1), while Cook Lake's ratio is the largest (18.7:1).
- ★ Land use in the watershed is mostly agricultural:

Agriculture	52%	Residential	10%
Forested	19%	Wetlands	4%
Open water	14%		

- ★ Riddles and Wawasee soils are the most common soils found in the watershed. These soils have a generally sandy loam texture and, in sloped areas, are prone to erosion.

For additional information on how to keep your lake and watershed clean and healthy contact:

Lake and River Enhancement Program
Indiana Department of Natural Resources
(IDNR) Division of Fish and Wildlife
402 West Washington Street Room 273
Indianapolis, Indiana 46204
(317) 233-3871
www.in.gov/dnr/fishwild/lare

Four Lakes-Lake Association
Plymouth, Indiana 46563
(574) 935-0544

Marshall County Soil and Water Conservation District
2903 Gary Drive
Plymouth, Indiana 46563
(574) 936-2024
www.marshallcountyswcd.iaswcd.org

This pamphlet was produced by:
JFNew
708 Roosevelt Road
Walkerton, Indiana 46574
(574) 586-3400

If you have any questions regarding the study or pamphlet, please contact JFNew.

Four Lakes Diagnostic Study

Marshall County

The Four Lakes Diagnostic Study is a comprehensive examination of Cook, Holem, Kreighbaum, and Millpond Lakes and their surrounding watershed.

The purpose of the study was to:

- ★ Evaluate historical trends in the lakes' water quality,
- ★ Describe the existing condition of the lakes and their watershed,
- ★ Identify problems, and make recommendations to address these problems.

Cook Lake:

- ★ Cook Lake is best described as a mesotrophic to eutrophic lake.
- ★ Cook Lake possesses poorer water clarity and higher total phosphorus concentrations than most Indiana lakes.
- ★ Historic evidence suggests that overall productivity increased in Cook Lake from the 1970s to 1995 before declining to levels observed during the current study.
- ★ Cook Lake supports a diverse emergent plant community. Two invasive species, Eurasian water milfoil and purple loosestrife, are also prevalent within the lake.

Holem Lake:

- ★ Holem Lake is best classified as a eutrophic lake.
- ★ Holem Lake possesses poorer water clarity and higher algal densities than those observed in most Indiana lakes.
- ★ Historic evidence suggests that Holem Lake typically possesses better transparency and lower nutrient concentrations than most lakes in Indiana.
- ★ Holem Lake supports the most diverse plant community present within the Four Lakes.

Kreighbaum Lake:

- ★ Kreighbaum Lake is best classified as a mesotrophic to eutrophic lake.
- ★ Kreighbaum Lake generally possesses lower nutrient concentrations than and similar transparency as most lakes in Indiana.

- ★ Historical records suggest water quality within Kreighbaum Lake has fluctuated but remains relatively similar over the past 35 years.
- ★ Kreighbaum Lake supports a diverse plant community with Eurasian water milfoil, coontail, white water lily, and spatterdock as the dominant species.

Millpond Lake:

- ★ Millpond Lake is best classified as a mesotrophic to eutrophic lake.
- ★ Millpond Lake possesses poorer transparency and lower nutrient concentrations and than most Indiana lakes.
- ★ Historical records suggest water quality within Millpond Lake has fluctuated but has changed little over the past 35 years.
- ★ Plants cover 94% of Millpond Lake. Eurasian water milfoil, coontail, bladderwort, cattails, and purple loosestrife are the dominant species.

How to Manage the Lakes:

The lakes have a relatively moderate residence time meaning that water moves through the lakes every 62 (Millpond) to 504 (Holem) days. The lakes also possess long shoreline interfaces meaning that activities directly adjacent to the lakes' shoreline have greater impacts to water quality within the lakes than activities farther out in the watershed.

Management Actions:

- ★ Develop an aquatic plant management plan in concert with Myers and Lawrence Lakes.
- ★ Investigate the use of alternate wastewater treatment systems.
- ★ Increase CRP enrollment.
- ★ Monitor/improve erosion control on development sites.
- ★ Restore wetlands.

What You Can Do:

Four Lakes' residents have substantial control over the health of their lakes!

- ★ Use only phosphorus-free fertilizer.
- ★ Plant native plants along shorelines.
- ★ Keep lawn clippings, leaves, and animal waste out of the water.
- ★ Clean/pump septic systems regularly.
- ★ Use idle speeds in shallow water.
- ★ Clean boat propellers after lake use; do not dump bait buckets into the water.